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The Licensing and Insurance Bill

THE Bill setting forth the Government's proposals for the licensing and insurance of nuclear sites was given a guarded reception during its second reading in the House of Lords. Carrying the short title " Nuclear Installations (Licensing and Insurances) Act, 1958," the Bill (in cumbersome and complex style) makes provision for regularizing the use of atomic energy by the generating authorities, industry and the Universities in the United Kingdom.

With the exception of the A.E.A. (later in the Bill mention is made of the fact that Government departments are also exempt) " no person shall use any site, for the purpose of installing or operating: (a) any plant designed or adapted for the production of atomic energy by a maintained controlled fission process; or (b) any other installation of such class or description as may be prescribed, being an installation designed or adapted for, or for the carrying out of any process preparatory, or ancillary to, the production or use of atomic energy or for the storage, treatment or disposal of nuclear fuel or other radioactive matter, unless a licence . . . has been granted . . . by the Minister " (of Power in England and Wales, the Secretary of State in Scotland). So general is the scope of (b) that a company (say) pressing plates for pressure vessels could require a licence for its factory. This is clearly an absurd case, but between the full-scale reactor and ordinary engineering procedure, there are a number of possible operations which may or may not be affected. For example will exponential experiments, laboratory experiments on fuel metallurgy, irradiation of materials with fission products and fuel element fabrication by industry all come into the licensing category? Lord Mills stated that the main intention is to control the building of reactors and, if this is so, it would seem that (a) and (b) could be conveniently grouped to cover controlled critical assemblies and perhaps installations where an incident arising from accidental criticality is not impossible—although the second class requires detailed amplification in terms of mass of fuel involved and its enrichment and need only concern natural uranium in very special cases.

The provision for grouping two or more installations into one unit is reasonable as associated with research reactors it is common practice to construct critical or sub-critical assemblies to provide physics data at zero energy. The clause which will allow the Minister *at any time* to impose conditions or to revoke the licence is, however, disturbing. This could mean that a project is agreed, funds made available, contracts placed and the plant built, but before operation the Minister insists that a major change be made, for example, containment provided, which completely alters the economics of the project. Some protection is clearly necessary.

Industry has scarcely been encouraged to enter the private reactor field, what with uncertainty of fuel availability and price and this would be a further sword hanging over its head, unless this clause is revised to limit powers to the planning phase, or to cover modifications to the plant.

Concentrating all third-party responsibility on the licensee is generally agreed to be the most satisfactory arrangement and allows the owner to assume complete control from the earliest construction stage. Insistence on insurance either through established funds or through the insurance market is also clearly desirable and the £5 million upper limit realistic (for a large reactor) and in accord with the insurance companies considered evaluation of the maximum incident. Should an incident seem to involve sums in excess of £5 million then claims would become the direct responsibility of Parliament. Such an incident would, of course, represent a national disaster and must be dealt with in these terms. It seems somewhat sweeping, nevertheless, to insist that insurance to cover £5 million be provided irrespective of the size of installation. We cannot really believe that a low-power package research reactor (such as is common in the U.S.) is an equal risk to a high-powered M.T.R. Admittedly the premiums need not be the same, but this does not help a concern which wishes to guarantee the liability from its own funds.

The proposal that licensees who are covering the third party risk, other than through the insurance market, shall not be required to cover more than two sites at one time, will presumably mean that the C.E.G.B. would provide its own coverage and, therefore, that the insurance companies will not be handling the power stations at all; this seems a rather unfortunate situation and somewhat illogical. We wonder if the full implications of this clause have been fully appreciated.

The clause which makes the licensee responsible for fuel during transit also needs examination. For the power stations it matters little whether the generating

authorities or the U.K.A.E.A. are held responsible for the transport of irradiated elements, but for small operators transport is a service that they would reasonably expect to be provided by the A.E.A. and they cannot clearly be held liable when the elements are in the Authority's charge.

It must be expected that claims should be considered for a period longer than that corresponding to the operation of the plant and the 10 years proposed seems a reasonable compromise between the 25 years suggested as the maximum time for carcinogenic effects and the length of time over which the history of a claimant can be accurately assessed. It might be fairer, however, and at the same time minimize the number of unreasonable claims, if the period were made for five years following the end of the licence or for 10 years following a recognized incident (or " occurrence " as the Bill has it) whichever is the later.

The Bill contains a clause making the registration of an occurrence obligatory, but what is an occurrence and should it not be defined, as fines for failure to register one are specified? This is not an easy question to answer and perhaps it would be better if it were left open, but some amplification would be advisable and some guidance should be given. Accessibility at all times by the approved inspectors is clearly necessary and, following an incident, a report should be drawn up or an inquiry held. Rather than leave it to the Minister's discretion as to how much should be published, would it not be wiser to make publication the rule, with provision in certain special cases—defined by the licence —for security to be imposed when installations of a military character are involved? Otherwise the public, Parliament and local authorities can be placed in an equivocal position.

Further consideration should also be given to the question as to whether in fact the Minister of Power is the most suitable authority. Inspectors must needs be recruited and, although there will be direct access to the Generating Board's expertise, this represents yet another Authority which will become involved in any private reactor project, and there are quite enough already. Should other reasons prevail, however, it would seem logical that the Safety Group at Risley should quickly be hived off from the U.K.A.E.A. and become responsible to Lord Mills, so that a unified control can be established.

In spite of its shortcomings this Bill is, nevertheless, to be welcomed as it represents the first real Parliamentary recognition of non-A.E.A. activities. It is up to both sides of the House to see that the necessary modifications are made speedily.

Research Reactor Specifications

AT the Geneva Conference, in addition to the working models, many designs of research reactors were on view. Whereas the U.K. is concentrating on three reactors, the Jason (produced by Hawker Siddeley and developed from the Argonaut), Merlin (by A.E.I.-John Thompson) and the Dido type (Head Wrightson Processes), a great number of companies in the United States are offering designs, particularly in the milliwatt to megawatt range and aimed specifically at the University and training market. A comment, however, that can often be heard is that, in spite of the variety of designs available, there is no single design that includes all the essential features that would be demanded by a single customer who was able to give a complete specification before the design progressed to an advanced stage.

Potential users of small reactors fall into several categories; the engineer, who wishes to study reactor engineering, the physicist who wishes to study reactor physics, the research worker who requires an intense source of radiation, such as the metallurgist, the chemist or the biologist, and then there are the group of workers who require ready access to a supply of short-lived isotopes. In many cases the demands of these groups are conflicting and no single reactor can satisfy the overall demands, except at a price that is quite beyond the means of even groups of universities or national institutes.

A second problem concerns the difficulty of bringing together the potential customer and the designer, at a sufficiently early stage in the design, to allow the manufacturer to include those features which will at least satisfy one group of research workers, and a group at that which is capable of utilizing the facilities of the reactor to the full.

There is no doubt that there is considerable interest in these small reactors and many American companies are relying for their current income on the sale of such machines. Equally certainly, however, there are many reactors which are not being used to anything like their full capacity and which represent highly expensive ornaments. This is more true in the United States than in Europe as European Institutions have lagged somewhat in their demands for critical assembly equipment and adopted altogether a more cautious approach.

In an effort to clarify the probable requirements of future customers and to provide a basis for future research reactor designs, *Nuclear Engineering* invites prospective users to define their requirements and to list those facilities which are considered desirable in a reactor which is either wholly owned by their own group or to which the group has access.

We invite group leaders and department heads throughout Europe to submit their requirements to *Nuclear Engineering* to enable us to establish a Forum where ideas on this subject can be exchanged.

DIGEST...

Surveying Significant News

Windscale No. 2 Not To Restart

Modifications to the Windscale pile No. 2 to bring it into line with the recommendations of the Fleck Technical Evaluation Committee would cost in the region of £500,000. In view of this the U.K.A.E.A. has definitely decided not to restart the reactor and the pile will be shut down. Fuel will be discharged and equipment outside the biological shield dismantled.

Modifications to Calder Hall and Chapelcross Fuel Channels

Details of modifications to be made to the fuel channels in the Calder Hall and Chapelcross reactors to eliminate the necessity for periodic Wigner releases have been given by Sir John Cockcroft in Japan. To increase the minimum graphite temperature by as much as 90° C, Magnox sleeves, leaving a stagnant air space will be fitted at Calder and No. 1 Chapelcross while graphite sleeves will be used in the three reactors at Chapelcross not yet completed; channels through the graphite stack will be enlarged to accommodate these graphite sleeves. It is estimated that over 15 years, stored energy will be less than 80% of the specific heat.

Euratom-U.S. Agreement Signed

The Euratom-U.S. agreement for co-operation, providing for a joint nuclear power research development programme to construct in the Euratom countries several large-scale reactors with a total installed capacity of 1,000 MW by 1963/65 was signed in Brussels on Nov. 8. The agreement must now go to the J.A.E.C. in the U.S. for final approval. Private industry in the Euratom countries can now submit proposals for reactor projects to Euratom and the U.S. government for inclusion in the power programme. (Details of the financial agreement and arrangements were published in *Nuclear Engineering*, August, 1958, p. 317.)

I.A.E.A. Advisory Committee Appointed

The decision taken on September 19 to establish a scientific advisory committee to the International Atomic Energy Agency has now been implemented. The seven members of the Board are drawn from India, the U.K., France, Brazil, Canada, the Soviet Union and the U.S.A.—Sir John Cockcroft representing the United Kingdom, Professor Rabi the U.S.A. and Professor Emelyanov the U.S.S.R. The first meeting of the Committee was scheduled for November 14 at which consideration would be given to the I.A.E.A.'s proposals for estimating world-wide distribution of hydrogen and oxygen isotopes in water, the establishment of the Agency's functional laboratory, long-range needs for technical facilities and additional research activities that might be handled by the Agency.

A.E.A. Evaluates Advanced Reactor Types

Present A.E.A. thinking concerning the reactor types most suitable for development to achieve competitive electricity generation with low capital cost, was summarized by Mr. P. G. Fletcher, deputy managing director of the Industrial Group, at a conference in Manchester at the beginning of November. He suggested that "the prospects of development of stations to be installed in the late 1960s and early 70s, must be viewed largely in terms of a choice between three possible types of reactor system: the gas-cooled reactor with graphite moderation, the gas-cooled reactor with heavy water moderation and the boiling water reactor." Potential savings would justify development costs of £40-50 million and as one prototype can be considered as costing some £20 million it could be concluded that the U.K. programme could justify two lines of development. The AGR is a clear first choice, whereas the potential value of the BWR is strongly dependent upon the feasibility of incorporating superheating. This is an intransigent problem. The BWR does, however, hold considerable possibilities for plutonium burning.

National Safety Advisory Committee to be Appointed

During the second reading of the Licensing and Insurance Bill, Lord Mills announced that a National Safety Advisory Committee is to be set up following consultations with the A.E.A., industry, insurers, owners and operators of major nuclear installations (i.e. the generating authorities) and organized labour. The relationship of this body to existing safety committees was not specified and it is feared that instead of crystallizing safety philosophy this body will represent "just another committee." It could, however, do much to establish safety practice on a real national footing.

Mounting Requirement for National Waste Disposal Service

Discussions on the responsibility for waste disposal arising from the Nuclear Installations (Licensing and Insurance) Bill will provide an opportunity for the machinery for a national scheme to be considered. Conscious of the steadily increasing demand for such a service, the Ministry of Housing and Local Government is already beginning to operate a temporary scheme with the assistance of Harwell, but at best this is a stop-gap and is scheduled to be in operation for only another nine months. This waste disposal must be placed on a proper footing at the earliest opportunity and regulations drawn up which take into account the considerable range of waste products that are involved. Local authorities should be able to take care of a considerable fraction, but there remains the intransigent material which requires proper treatment and, although the A.E.A. appears reluctant to assume long-term responsibility for this chore, there is every reason why the Authority should be instructed to make its considerable facilities for waste disposal nationally available. The new licensing body could be instructed to organize the scheme and handle the liaison work with the other Ministries. We understand that the technical report dealing with this subject is now completed, and we hope that Parliamentary action will be taken soon.

Factory Regulations Governing Radioisotope Usage Needs Speeding

But we gather that this is unlikely. The first draft Factories (Ionizing Radiations) Special Regulations were published 15 months ago, but it is apparent that so many modifications have been suggested that the next stage will be merely a new draft. At least the Ministry is allowing interested parties a proper opportunity to comment, but the department concerned is so absurdly understaffed that long delays are inevitable. It is perhaps not appreciated how great a hiatus this delay is causing in the industrial application of radioisotopes, and how much unrest and serious financial loss is resulting. Also with the advent of the new licensing bill there is bound to be a great deal of overlapping of ministerial responsibilities, particularly in establishments installing research reactors, and this will further increase the load on the Ministry of Labour. These factory regulations should be taken a lot more seriously and much more effort allowed the department concerned.

A.E.C. to Promote Fuel Cycle Development

The U.S.A.E.C. has invited industry to submit proposals for the development programme aimed to cut by substantial amounts costs inherent in present fuel cycles. Proposals are requested concerning development of chemical processes, development of fuel element materials and designs, irradiation and post irradiation development, fabrication and inspection techniques, testing of fuel elements and selection of proven types.

The *Unclear Times* Third Edition

The proprietors and policy directors of the *Unclear Times* have in the past, occasionally been accused of a somewhat frivolous attitude towards the dangers of nuclear radiation and the unpleasant consequences of over-exposure. It cannot be denied there is some justification for this view but, at the same time, it is felt that the sooner this subject can be discussed and considered at any level rather than on the emotional plane to which it so often descends, the more realistic can be the safety measures that are developed and, paradoxically the more readily will these measures be accepted by those workers in the field who are genuinely exposed to the dangers from nuclear radiations. However, to anyone who considers that all levity concerning radiation dangers is inevitably in bad taste, we feel that none of the *Unclear Times* will appeal.

Reactor Briefs

The first reactor at Chapelcross diverged on Nov. 9 and will be progressively brought up to its full power of 200 MW(t). . . . ALPR, the Argonne National Laboratory's package 3MW(t), 200 kW(E) and 400 kW (heating) BWR to be dedicated at N.R.T.S. (Idaho Falls) on Dec. 2. . . . Geesthacht (nr. Hamburg) 1-5 MW swimming pool reactor inaugurated, Oct. 28.

REACTOR SHIELDING ANALYSIS

By C. C. HORTON
(*Rolls-Royce Ltd., Derby*)

The design of biological shielding for reactors has made rapid progress from the early rule-of-thumb methods. This article reviews the problems presented, the general state of shielding analysis, and the way in which it differs from core design analysis.

IT is probably fair to say that methods of reactor core analysis have not changed, except in refinement of detail, during the past decade. Methods of shield design, however, have evolved from the era of "mysticism and witchcraft" to what might be termed approximations supported by a wealth of data and experience. It is the purpose of this review to indicate the present state of knowledge in the field and to point out the essential differences between shielding analysis and core design physics. In order to keep the survey as simple as possible a deliberate attempt has been made to omit all mathematics from the discussion; the reader who finds himself intimidated by the solitary equation which is presented may comfort himself with the observation that the efforts devoted to its solution have run to many millions of man-hours and volumes of published literature.

Characteristics of Shielding Problems

A reactor generating a heat output of 100 MW produces a radiation field in the surrounding environment ranging up to some 10^6 rad/h in the form of neutron and gamma radiation. The problems presented to the shield designer are those concerned with reducing this radiation field to a level tolerable to the operating crew,* and removing the heat dissipated in the process. In surveying the present status of shield design, it is of interest to examine the characteristic features of the problems which are presented, and the respect in which they differ from those posed by the design of a reactor core.

The transport of radiation (neutrons or γ-radiation) is described fundamentally by the Boltzmann transport equation.

If:

μ is the total cross-section at energy E;

$\Sigma(\Omega,E)$ is the scattering cross-section;

$\bar{\Omega}$ is a unit vector in the direction of N;

S is the source strength per unit volume;

N is the angular number flux in the energy range E to $E + dE$; i.e., the number of particles at $\bar{r}$ with energies between E and $E + dE$ travelling in the direction $\bar{\Omega}$ which cross, in unit time, a unit area at right angles to $\bar{\Omega}$.

then:

$$\nabla \cdot \bar{\Omega}N + \mu N = \int\int N(\bar{r},E',\bar{\Omega}')\,\Sigma(\bar{\Omega}'-\bar{\Omega},E'\rightarrow E)\,dE'\,d\Omega' + S(\bar{r},E,\bar{\Omega}') \quad . \quad . \quad . \quad (1)$$

The two terms on the left represent the net loss of particles per unit volume by leakage and collision. The terms on the right represent the net gain due to sources and scattering from other directions or angles. Note that the equation involves N, its differential, and its integral over E and Ω; in general, solutions are then obtainable only by numerical means.

It is worthwhile emphasizing at this point that equation (1) is absolutely fundamental and accurately describes the transport of both neutrons and γ-rays in any arbitrary medium. In principle, if the behaviour of all the constants were known accurately over the entire energy range of interest, an accurate solution of any problem in reactor core or shield design could be obtained. The difficulties which accompany the solution of the transport equation are those of mathematical technique or lack of knowledge of fundamental data; we shall see presently how these difficulties are magnified in the problems peculiar to shield design.

In reactor core analysis one begins by separating the neutrons present into several energy groups. One is always a "thermal" group in which the neutrons have reached a state of kinetic equilibrium with their surroundings; the others are either a set of groups of given energy so that the slowing-down process is represented by discreet energy jumps with a quasi-equilibrium diffusion in each group, or a single group in which slowing down is imagined to take place in a smooth continuous way. Either artifice enables one to remove the energy dependence of (1) or to simplify it considerably by expanding the flux in a Taylor series terminated at the second term (age theory). In the latter case it is required that the scattering cross-section does not vary sharply with energy.

The next step is then usually to express the angular dependence of the scattering cross-section and the angular dependence of the flux into a series of Legendre polynominals; termination of these series after the first two terms and neglect of the ratio Σ^*/Σ_s then leads to the diffusion theory. Better transport theory approximations are obtained by retaining more terms at the expense of considerable increase in computational labour. In either case above it is assumed that the contribution of uncollided source neutrons is small and that large discreet losses of energy (inelastic scattering) are rare.

Even so, the equations obtained in the simplest approximation of diffusion theory are second order differential equations. No analytical solution is possible in three dimensions except in the simplest case of a spherical core, and reasonable approximations are valid only for cores of considerable symmetry.

In the analysis of a core by one of the conventional group methods, then, one is forced to make the following approximations to obtain reasonably convenient solutions:

(a) Simple scattering properties of the nuclei (small number of terms in the Legendre series).

(b) Angular flux distribution nearly isotropic (small number of terms in the Legendre series).

(c) Continuous slowing-down model, or one-velocity model (small number of terms in Taylor series).

(d) Small dependence of scattering cross-section with energy.

(e) Small ratio of capture to scattering at any energy.

(f) No significant contribution from uncollided neutrons.

(g) Simple geometry of system (maximum possible symmetry).

* The maximum permitted level for normal occupational work is 0.3 rad/week.

This is indeed a formidable list of approximations; even so, the difficulties experienced in reactor design are well enough known. On turning to the problems encountered in shielding design, however, nearly all of the approximations listed above become invalid. This state of affairs arises for the following reasons. First, by definition there are no sources of radiation inside a shield† and thus a very pronounced anisotropy of the flux exists. Moreover, the lack of sources emphasizes the importance of the uncollided flux in that it provides a distributed source of radiation at lower energies. Secondly, the importance of a given particle (neutron or γ-ray) depends in a different way on its energy and direction. In the reactor core the importance of a neutron or γ-ray depends only to a small extent on its direction or energy; in the shield, the importance of a particle depends greatly on whether it is travelling towards the outside of the shield or not. This situation arises for

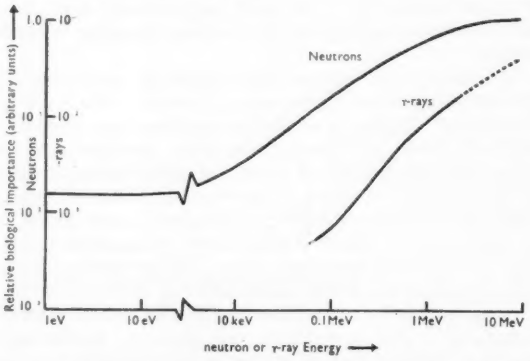


Fig. 1.—Relative biological importance of neutrons and gamma rays. The relative biological importance refers to flux of 1 neutron or gamma ray/cm², sec.

several reasons: (a) energetic neutrons or γ-rays are biologically much more significant than those which have lost energy by scattering and thus change of direction (Fig. 1); (b) the pronounced forward scattering at the biologically significant higher energies enhances the importance of those neutrons or γ-rays that take the shortest path through the shield. Thirdly, a shield is deliberately made to have as high a capture cross-section as possible, and finally the geometry of a shield is inevitably complicated by the presence of coolant pipes, charging devices, experimental holes and other aids to shielding ulcers. Experimentally, the effort needed to predict the performance of a reactor core is eased by the repetitive nature of the reactor lattice and the fact that the spatial neutron distribution is effectively power independent. Small critical assemblies and the exponential experiment can thus yield the required data without the complication of work at high radiation levels. In a shielding experiment, the characteristic behaviour of the flux varies with shield penetration, and the radiation levels which the shield is designed to allow are near the lower limit of sensitivity of many common detectors. The radiation source required is then inevitably of the same order of magnitude as that for which the shield is designed and full-scale mock-ups of the sample are necessary.

In such circumstances the comment which should be voiced is not that it has taken 15 years to develop a reasonably accurate model of shield analysis, but that one has been developed at all. Fortunately, however, considerable simplification of the problems can be made in most practical shield materials. First, the total neutron cross-section of hydrogeneous shields and the total γ-ray cross-section of all‡ shielding materials tend to increase with decreasing radiation energy (Fig. 2). Thus the direction of the radiation and the distance it travels before the first collision tends to be the dominating factor in determining the shape of the alternative curve. Secondly, in such shields, the energy loss per collision is high, and since the biological dose-rate is strongly dependent on the "hardness" of the radiation, this factor tends to reinforce the importance of the uncollided flux. It is somewhat ironical to observe that these very factors which prevent the application of conventional diffusion theory approximations to shield analysis help considerably in understanding the physics of the attenuation process and lead to quite simple semi-empirical rules.

It is still necessary to resort to numerical solution of the transport equation in order to obtain reasonably accurate results, but the labour required is reduced considerably by the characteristics described above.

In a non-hydrogeneous shield, the neutron energy loss per collision is small, and the importance of the uncollided flux is consequently reduced. There exists, as yet, no satisfactory analysis or experimental results for such shields. In practice, of course, it is usually desirable and convenient to introduce some hydrogen into a shield to improve the neutron attenuation characteristics, so that this void in our understanding is not of such serious consequence. The experimental difficulties associated with measurements on such materials are formidable indeed; for example, an experiment to investigate the behaviour of the neutron flux at large distances from the source in pure iron might require an iron slab some 4 ft × 4 ft × 4 ft, that is about 15 tons of iron.

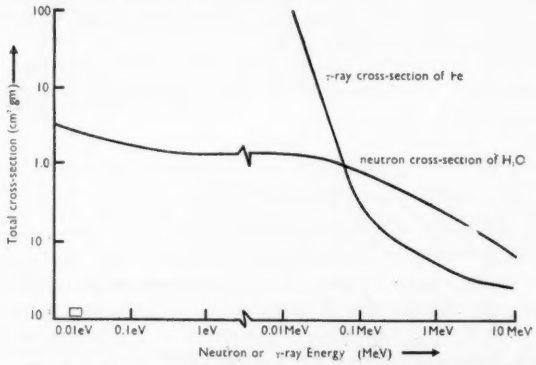


Fig. 2.—Total cross-section for neutrons and gamma rays.

Shielding of γ-radiation

The γ-ray shielding problem has been the subject of an enormous amount of work, both theoretical and experimental. At the present time, it can be remarked that methods and data exist which enable shielding problems to be solved for most practical cases with the accuracy required. As we have noted above, a solution to a radiation transport problem requires four items of fundamental data. These are:—

(1) A knowledge of the variation of the interaction cross-sections with the direction and energy of the incident radiation.

(2) A knowledge of the mechanism by which energy is lost during collisions.

† Strictly speaking of course, this is not true, especially in consideration of the n,γ reactions. But such sources are most important at the inside of the shield and do not affect this argument.

‡ Except those of high atomic number, in which case the penetration is determined by the radiation at the energy for which the cross-section is a minimum.

(3) A knowledge of the energy spectrum of the sources concerned.

(4) A specification of the relation between radiation flux and biological effect. This specification depends mainly on the data of (1) and (2) above, but depends also on the importance which is to be assigned to the mechanism of energy loss. For example, a proton dissipates energy in a much smaller volume of body tissue than does an electron of the same energy. The damage produced is the more difficult to overcome by the body tissues; in consequence, a proton beam is reckoned to be 10 times more effective than an electron beam which dissipates the same total energy.

The mechanism of the interaction of γ-rays with matter is thoroughly understood. Since nearly all γ-ray interactions of interest are interactions with the electrons surrounding a nucleus or the Coulomb field of the nucleus, they may be investigated by the well-tried tools of quantum mechanics and do not involve an understanding of the structure of the nucleus itself. The interaction cross-sections can thus be evaluated from a knowledge of the properties of electrons moving in the electric field of the nucleus, and extensive tabulations have been made. Experimental determinations of the cross-section behaviour show that these calculations are accurate to within a few per cent. for all nuclei. Apart from the rather arbitrary assignment of relative biological efficiency referred to, then, the properties listed (1), (2) and (4) above are well-known, and vary smoothly from one element to another and are available for feeding into shielding calculations.

The sources of γ-radiation are transitions from one energy state to another in the nucleus itself; in consequence,

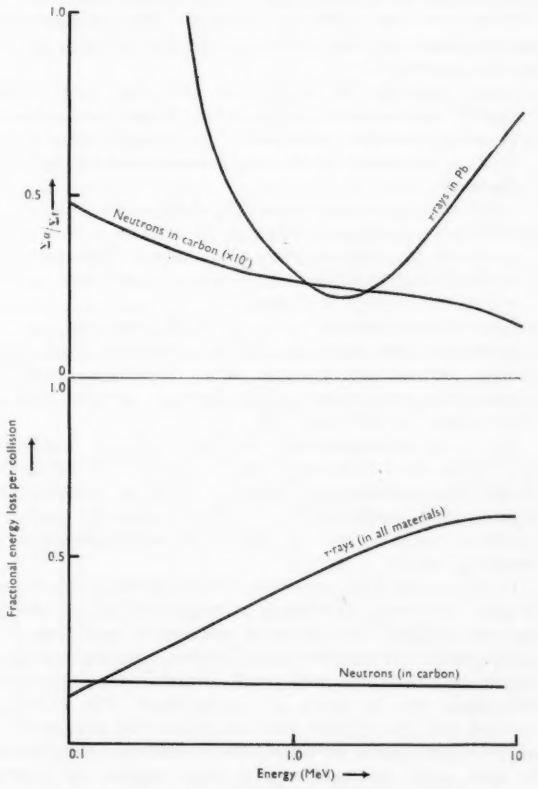
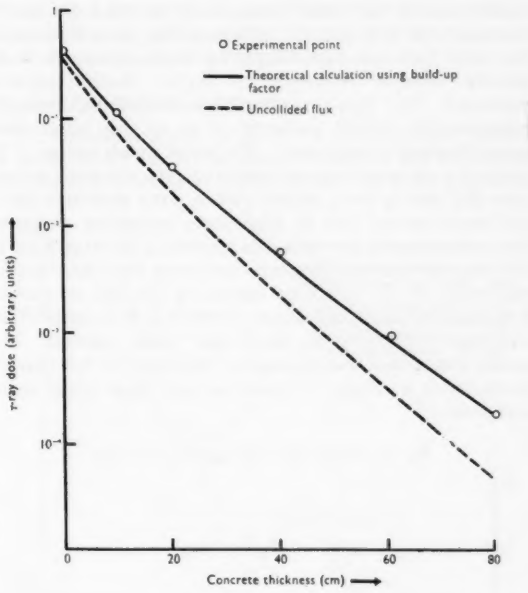


Fig. 3.—Energy degradation and absorption probability for gamma rays and neutrons.

Fig. 4.—Attenuation of 6.1 MeV gamma rays in ordinary concrete.



the γ-ray spectra which form the sources in a radiation shield are much less well understood. However, the capture γ-radiation from most of the elements and the γ-radiation emitted in fission and the decay of fission products have been the subject of much experimental work over the past decade. Although some considerable uncertainty still exists in the data available for the fission process, the results obtained are sufficiently accurate in most cases to be a secondary source of error compared with geometrical complexities and approximations in the methods used.

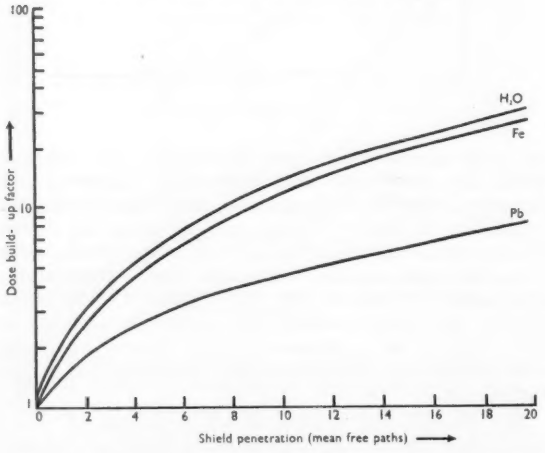
The distinguishing features of the interaction of γ-rays with matter are the large energy loss suffered per collision and the high probability of absorption at each end of the energy range of interest. Fig. 3 illustrates these quantities for a good γ-ray shield in comparison with neutron interaction in a typical non-hydrogeneous reactor material (graphite).

These features do not allow any of the conventional diffusion approximations common in neutron transport theory to be made. Two other methods have been used with success, the Monte Carlo method, and the " moments " method. The Monte Carlo, or random sampling, method consists essentially of following individual γ-rays through a whole life history. At the first collision, the direction of the scattered photon or the chance of absorption are selected by a random process using the properties of the medium concerned. This process is repeated until the photon finally disappears and the results of many such histories combined to obtain the spatial behaviour of the flux. The method suffers from the disadvantage that the number of histories which must be compiled increases with the attenuation factor required; for example, some ten thousand must be considered to obtain reasonable accuracy for a shield attenuation of about 100. It is, however, the only method capable of dealing with multi-layered shields, or extremely complex geometries.

The moments method forms the backbone of shielding analysis at the present time. In this method, the flux and reaction cross-section are expanded into spherical harmonic

series. The moments of the angular flux§ are now formed, and a series of integral equations derived for them. These equations may be solved numerically to yield the desired moments. It is important to note at this point that, unlike the usual harmonic expansions, the moments can be found exactly without reference to higher order neglected moments. The flux may then be reconstituted from the moments by several methods; it is at this point when approximation is necessary. The chief disadvantage of the method is its restriction to infinite shields, although we may note that this is not a serious one in γ-ray problems due to the large energy loss in high-angle scattering collisions. The advantage of the moments method is illustrated by the fact that attenuation problems involving flux reductions of the order of 10^{-8} may be solved by the use of perhaps 8 moments at most, the labour involved is thus considerably less than is required in the Monte Carlo method. It is worth noting that the calculation required for this example corresponds to about 15 minutes on a high-speed digital computer.

Fig. 5.—Dose build-up factors at 2 MeV.

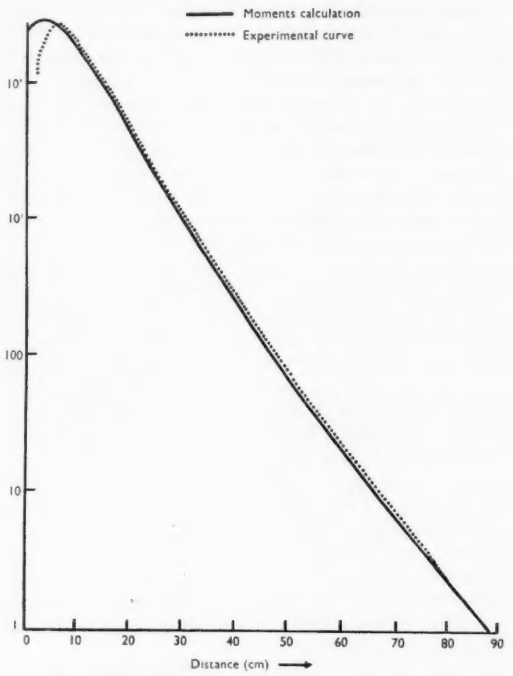


We have noted above that in shielding theory considerable weight is given to the uncollided flux. Fig. 4 illustrates how the behaviour of the uncollided flux determines the general characteristics of the attenuation curve. A natural way of presenting the results of accurate calculation then, is by the use of "build-up factors"; such factors are essentially corrections to the uncollided flux to allow for multiple scattering. The advantage of this presentation lies both in its aid to physical understanding and the fact that the build-up factors are slowly varying functions of energy, atomic number and attenuation (Fig. 5). Thus an accurate calculation of the penetration of γ-rays in perhaps six materials taken at judicious points from the periodic table of elements is sufficient to enable most problems to be evaluated by extrapolation. The elements for which calculations of this kind exist in detail are water, aluminium, iron, tin, tungsten and lead. Water, aluminium, iron and lead, of course, are important in their own right; the addition of tin and tungsten facilitates extrapolation in the case of such elements as barium, which are commonly used in high-density concretes.

§ If I_l is the lth term in the expansion of the flux, and Z the space co-ordinate, the mth moment of the flux is proportional to

$$\int_{-\infty}^{+\infty} I_l . Z^m . dZ$$

Fig. 6.—Moments calculation of neutron flux at 1.44 eV from a point fission source in water.



Shielding of Neutrons

In comparison with the wealth of data obtained for the solution of γ-ray shielding problems, the corresponding neutron data are rather meagre. This situation arises for several reasons:—

(a) Although the mechanism of energy loss is well known, the behaviour of the cross-sections varies sharply from one element to the next. It is not possible, therefore, to interpolate easily between solutions for different elements.

(b) Except in hydrogeneous shields, the capture to scattering ratio is so small that the neutron makes many hundreds of collisions in slowing down. The behaviour of the unscattered flux is thus of less importance, so that a build-up concept is of little value.

(c) Experimentally, the neutron attenuation in commonly used materials such as concrete is much more rapid than for the reactor γ-rays. There has, therefore, been little incentive to make a thorough study of neutron behaviour in such materials.

For non-hydrogeneous shields, several analytical approaches have been suggested to describe the behaviour of the flux at deep penetrations. There is, however, no experimental confirmation of these methods, and this problem remains one of the least well-understood in shielding theory.

In the case of hydrogeneous shields, however, the picture is quite different. Hydrogen is unique in that the energy loss per collision in a neutron reaction is very large. In consequence, the number of collisions a neutron undergoes before capture is relatively small, and the behaviour of the uncollided flux is again of importance. The moments method may be applied with success to the prediction of neutron attenuation in water shields, and has been shown to give quite accurate results over regions of interest (Fig. 6). The method has not, however, been applied to mixtures of hydrogen and other nuclei as in concrete.

An extremely valuable semi-empirical approach to the problem of multi-layered shields of water and non-hydrogeneous materials is the so-called " removal cross-section " method. The success of this method relies on several properties of hydrogen. First, the rapid decrease of the hydrogen cross-section in the energy region 10 keV upwards produces a situation in which the mean free path of the source neutrons is some 10 times greater than neutrons which have suffered several collisions. Secondly, the slowing down of neutrons below the source energy is so rapid that a quasi-equilibrium of neutrons at all energies is set up. Thus, after a fairly short shield penetration the neutron flux at all energies (in particular, the thermal flux) bears a constant ratio to the flux of uncollided neutrons.

If, then, the flux distribution in a water shield is known (either by calculation by the moments method or by experiment) the effect of inserting a layer of any other material can be calculated simply. The flux of uncollided neutrons is reduced by the layer in a manner calculated by a simple exponential absorption formula using the total cross-section for the uncollided flux and, provided that sufficient water is present following the layer to re-establish the equilibrium spectrum, the total flux is reduced by the same amount. A complication is the phenomenon of pronounced forward scattering at high neutron energies in the source region; this has the effect of apparently reducing the cross-section of the uncollided neutrons by some 30%. The effective cross-section to be used is called the " removal cross-section "; experimental values for some elements are given in Fig. 7. Theoretically, the removal cross-section should be calculable from a knowledge of the total cross-section, the energy spectrum, and the angular distribution of the scattered neutrons; practically, however, the angular distribution is so poorly known that attempts so far have met with little success.

The existence of an equilibrium spectrum which is fairly quickly restored near to a slab which perturbs the flux distribution leads one to suggest the use of multi-group neutron diffusion theory to predict the detailed changes in the scattered flux in and around the slab. The reason for this suggestion is essentially that the mean free path of the uncollided flux is much larger than the diffusion length of neutrons at thermal energies. These neutrons have an almost constant spatial source distribution and thus the flux is sufficiently isotropic for the diffusion approximation to hold. Experimental evidence from published data tends to support this approach (Fig. 8).

A similar hypothesis has been put forward as a method of treating hydrogeneous materials like concrete. Here it was assumed that the spatial distribution for neutrons scattered below the MeV region could be found by a multi-group analysis using neutrons scattered out of the uncollided flux as a continuous source through the shield. The method was found to predict the shape of the observed flux distribution satisfactorily, but an absolute numerical fit to the data was not attempted.

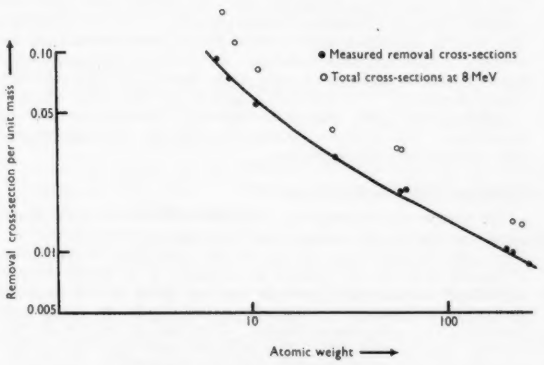


Fig. 7.—Removal cross-sections.

Problems of Bulk Shield Design

The optimum shield design for a given reactor depends so much on the size of the plant, the duty it has to perform, and the site in which it is placed that it is quite impossible

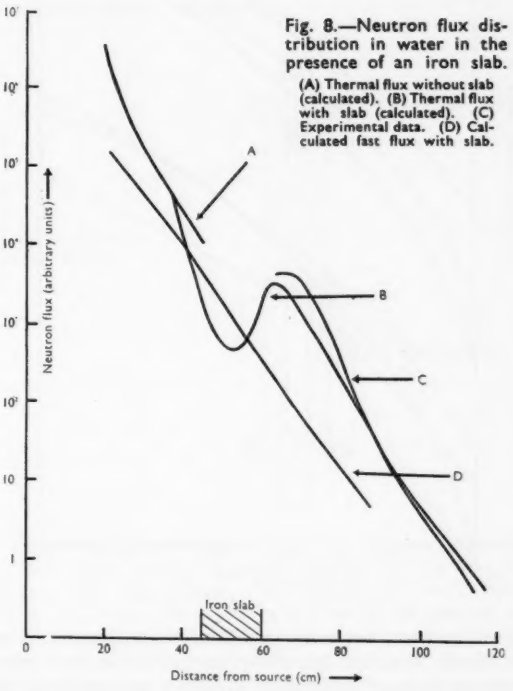


Fig. 8.—Neutron flux distribution in water in the presence of an iron slab. (A) Thermal flux without slab (calculated). (B) Thermal flux with slab (calculated). (C) Experimental data. (D) Calculated fast flux with slab.

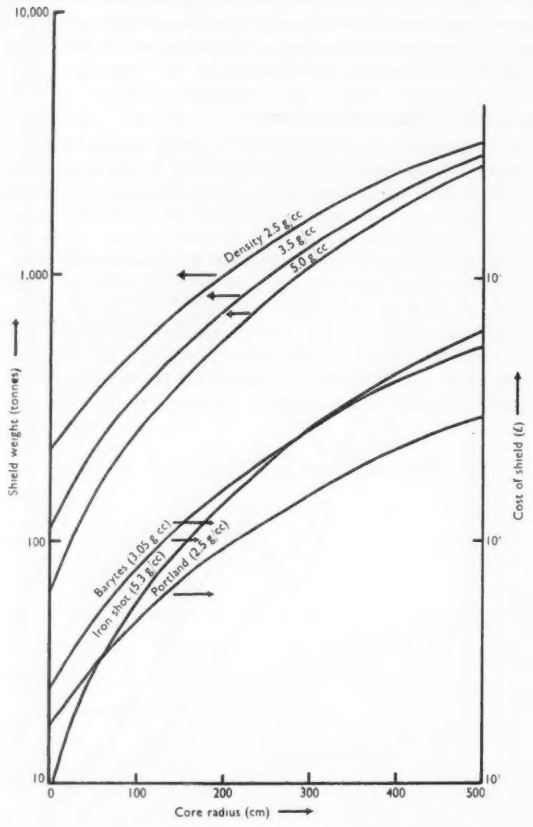
to formulate a set of rules to guide the designer. For example, it is almost always cheaper to build a concrete shield using locally quarried aggregate for the mix than to transport a specially dense aggregate from some distance away, even though the saving in thickness offered may seem attractive. On the other hand, if the reactor is to be enclosed in an airtight shell or a vessel, the designer may find that the increased cost of a special aggregate is more than compensated by the savings in building and foundation costs.

The shield must necessarily consist of a mixture of hydrogeneous and heavy materials; the materials which are then available are concretes or mixtures of metals and water (or other similar hydrogen compounds such as polythene or oil).

Concretes have many advantages. The density of a concrete may be varied between wide limits (2.5 g/cc to 5.5 g/cc have been achieved in recent practice), it has been the subject of several full-scale shielding experiments, and is a material thoroughly familiar to the constructional engineer. Moreover, it is cheap and needs relatively unskilled labour for its erection. Fig. 9 illustrates the merits of several different types of concrete in shielding an idealized spherical system; it can be seen that for the great majority of land-based power plants the normal " Portland " concrete is a perfectly satisfactory material.

The greatest uncertainty in the design of a concrete

Fig. 9.—Weights and costs of concrete shields.



shield at present lies in the problems of heat removal from the shield. Concrete has a low thermal conductivity which gives rise to large temperature gradients and stresses under quite moderate heat inputs. As a rough rule of thumb, a heat input of 1 B.t.u./ft², h produces a temperature rise of about 1°F in a normal concrete reactor shield. The problems that arise are twofold. In the first place, the rise in temperature tends to drive off some water present in the concrete. Although this undoubtedly has some deleterious effect on the neutron shielding properties of the material, concrete is such a relatively poor γ-ray shield compared with its neutron attenuation properties that there is normally a reasonable margin of safety present in the design to allow for this event. Secondly, the resultant mechanical stresses can produce cracking of the concrete with the possibility of failure of the structure. Reinforcing can be used to overcome this difficulty, but at temperature rises of 90°C or so, the amount of reinforcing needed becomes prohibitive and it is better to concentrate the reinforcing material at the front face of the shield as a separate thermal shield. It is doubtful if the presence of cracks forms a hazard at all, in that the crack must present a straight path through the shield to be a radiation nuisance and the concrete seldom bears much load in addition to its own weight. It has been argued that creep in concrete may relieve some of the stresses set up, but this is a topic which is, as yet, rather poorly understood. Apart from the obvious and well-tried procedure of facing the concrete with a separate thermal shield to reduce the heat input, no other means of alleviating this problem, if it really is a problem, have been tried.

The use of heterogeneous mixtures of water and metals offers the advantage of the minimum weight or thickness shield. By concentrating the dense material which is most effective in γ-ray shielding on the inside of the shield it is possible to reduce the overall weight considerably on a small system. Similarly, by reducing the proportion of hydrogen in the shield to the absolute minimum necessary to ensure thermalization and capture of the neutrons scattered from the uncollided flux it is possible to design the minimum thickness shield. Inspection of Fig. 9, however, shows that the advantages to be gained are quite small except for small reactors, so that such shields have not hitherto been employed outside the military field. In shields for small high-power reactors one is faced with a new set of problems. The small volume of the reactor implies a much larger leakage of radiation into the shield and problems of heat generation and radiation damage become more serious. Most hydrogen compounds undergo sizeable physical changes in high radiation fluxes, and these changes are often accompanied by the liberation of gases which may collect in some portion of the shield and form "holes" in it. Neutron-induced embrittlement of the pressure vessels commonly used in small power reactors may become a serious problem and it may be necessary to transfer some of the shield inside the pressure vessel to avoid this difficulty. The cost of metal-water shields is much greater than that of concrete ones due to the use of specialized techniques in erection and the cost of the materials themselves.

Little published detail is available on the problems associated with special shields of this kind, but it seems likely that the main difficulties are those of heat generation and radiation damage mentioned.

Acknowledgments

Figs. 4 and 8 are taken from Rockwell, USAEC report TID-7004 (1957), fig. 6 from J. Certaine and R. Aronson, American report NDA-15c-40 (1954), and figs. 7 and 9 from "Radiation Shielding," Price, Horton & Spinney (Pergamon Press, London, 1957).

Blindage Contre la Radiation

La conception du blindage biologique pour les réacteurs a fait des progrès rapides depuis les méthodes empiriques du début. Le présent article passe en revue les problèmes soumis, l'état général de l'analyse du blindage, et la façon dont elle diffère de l'analyse du dessin du noyau, vu que la plupart des approximations employées pour le dessin du noyau cessent d'être valables lorsqu'elles sont appliquées au blindage. Néanmoins, il est possible de concevoir un blindage dans des limites de précision raisonnables; la plus grande incertitude qui reste se trouve dans le domaine de l'élimination de la chaleur.

Abschirmung gegen Strahlung

Die Konstruktion der biologischen Abschirmung von Reaktoren hat seit der ersten Periode, in der man nach Faustregeln arbeitete, grosse Fortschritte gemacht. Der Aufsatz gibt eine Uebersicht über die vorhandenen Probleme, über den allgemeinen Stand der Theorie von Abschirmungen, und in welcher Weise diese sich von der Theorie der Konstruktion eines Kerns unterscheidet, da die meisten Annäherungsbestimmungen, die bei der Kernkonstruktion benutzt werden, nicht gültig sind, wenn man sie auf die Abschirmung anwendet. Nichtsdestoweniger ist es möglich, Abschirmungskonstruktionen innerhalb zulässiger Grenzen genau zu berechnen. Die grösste Unsicherheit besteht noch immer auf dem Gebiet der Wärmeabfuhr.

Blindaje Contra la Radiacion

Ha habido rápido progreso en el diseño del blindaje biológico para reactores desde la época de los primeros métodos empíricos. Este artículo hace una revista de los problemas presentados, el estado general del análisis de blindaje, y la forma en que difiere del análisis del diseño de núcleos, desde que la mayoría de las aproximaciones empleadas en el diseño de núcleos es inválida al ser aplicada a blindaje. Con todo, es posible diseñar blindaje dentro de límites razonables de exactitud. La mayor incertidumbre que todavía queda está en el campo de la eliminación de calor.

An Ultimate Safety Device for Thermal Reactors

By A. C. HUGHES, B.Sc., A.M.I.Mech.E.
(*Hawker Siddeley Nuclear Power Co., Ltd.*)

MOST reactors are controlled and protected by means of absorbing rods which move in response to commands injected from outside the reactor. Such movements may be automatically or manually initiated. The circuits are normally designed such that circuit faults and power failures lead to a reactor shut-down and the possibility of operating the reactor with an unreliable safety system is remote. Nevertheless it is not unreasonable to consider some additional safety device, particularly if this has a completely different mode of operation and would not be affected by such disturbances as might render the normal systems inoperative.

The device described in this article is entirely automatic and requires no external signal. It is temperature-sensitive and will shut down the reactor when components reach a dangerously high temperature. It is, therefore, particularly useful in providing additional safety for reactors which may have a positive temperature coefficient of reactivity.

The Phase-change Device

The basis of this device is that material which is a high absorber of thermal neutrons is placed inside the reactor but in such a form that the poisoning effect on the reactor is very small at normal operating temperature, but considerable above some predetermined "danger" temperature. This can be achieved by choosing a highly absorbing material in a solid or liquid state, which is arranged to have a small surface/mass ratio (e.g., of spherical form) so that the effective absorption cross-section is very much less than the potential cross-section in the dispersed state. To meet particular conditions it is necessary to choose a material which changes to the gaseous state (and thus disperses) at the required temperature. It is desirable to disperse the materials inside a container which can be easily removed so that the effect on the reactor is not necessarily permanent.

Application to Calder-type Reactors

Since any power surge will give rise to an instantaneous increase in the uranium temperature the maximum protection will be obtained if the device is designed to respond rapidly to changes in the uranium temperature. A suitable "danger" temperature could be 650°C, allowing an adequate margin above normal operating temperature.

A device for these reactors should have the following characteristics:

1. The effect on the neutron economy during normal operation must be small so as not to prejudice the economics.

2. The effect on the neutron economy when the centre uranium temperature exceeds 650°C must be large enough to shut down the reactor.

3. The response must be sufficiently rapid to arrest the diverging characteristics before the system is damaged.

A suitable absorber for this application is mercury. In the particular design described, the quantity of absorber is chosen such that the poisoning effect on the element above 650°C is about 2%. Below this temperature the poisoning effect is 0.3% and additional reactivity must be provided to override this. Greater or lesser quantities of absorber can be accommodated as required.

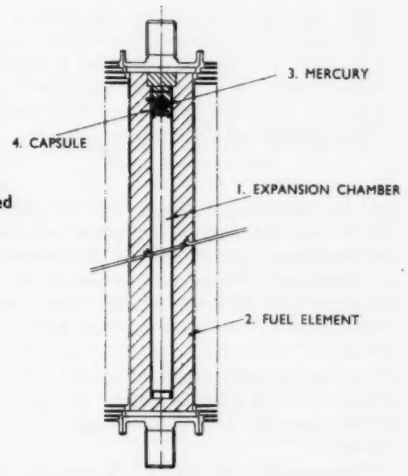


Fig. 1.—Unit applied to fuel element.

The device is illustrated in Fig. 1. The expansion chamber (1) fits closely inside a small central hole in the fuel element (2). The present fuel elements are solid but it seems likely that the effect of a hole of the desired size would be negligible since the decrease in thermal utilization would be balanced by an increase in resonance escape and the net change in reactivity is almost zero. It is proposed that all fuel elements should be fitted with the device to eliminate complications in fuel shuffling and to protect the reactor from local overheating.

The absorbing material, mercury (3), is contained within a spherical cavity in a sealed capsule (4). At atmospheric pressure mercury boils at about 360°C but if contained the vapour pressure rises steeply with temperature. In the range of interest the relationship is shown in Table 1 and illustrated graphically in Fig. 2.

The capsule is designed to burst when the pressure inside reaches 35 atm. Since the inside of the expansion chamber will be initially pressurized, the capsule is designed to burst when the pressure difference across the wall is less than 35 atm. If some tolerance can be allowed on the bursting temperature it is obvious from the pressure curve that the bursting pressure is not very critical; a margin of 50°C on temperature provides a margin of 12 atm on the bursting pressure. The dimensions of the chamber have been chosen so that the pressure increase in the chamber when the device operates is 20 atm. This pressure can be easily supported if the chamber is made of niobium 0.005 in. thick. This material is compatible with mercury and with uranium at these temperatures and it has a suitably low neutron absorption cross-section.

Reliability

It has already been shown that a considerable margin in bursting pressure is permissible so that the design and

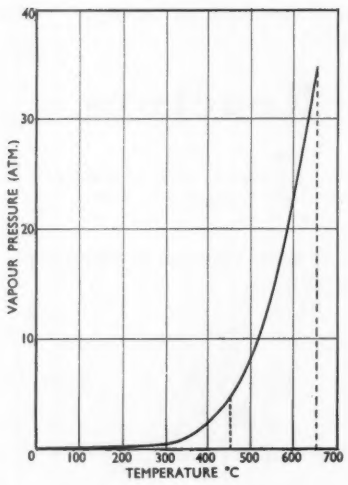


Fig. 2.—Variation in mercury vapour pressure with temperature.

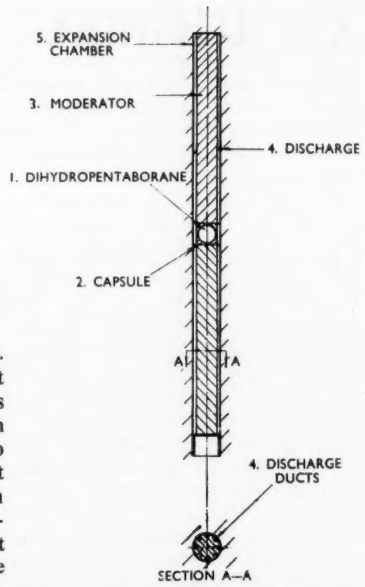


Fig. 3—Unit applied to small research reactor.

performance of the capsule is not very critical and some uncertainty about the effects of corrosion and neutron damage can be tolerated. There are a number of materials that exhibit little or no corrosion with mercury at these temperatures and with the use of inhibitors this range can be considerably extended. It should be noted that both corrosion and neutron damage will tend to reduce the temperature of operation so that the device can be considered to "fail-safe." To reduce the chances of premature discharge all capsules manufactured would be tested up to temperatures slightly in excess of the normal operating temperature and a fair percentage of a production batch "fired."

The possibility of leakage of mercury from the capsule still remains. The effects of leaks in one or two units will not be large, one break corresponding to a change in $\delta k/k$ of less than 10^{-5} and it would not be necessary to remove them from the reactor immediately. Some method of detecting leaks and premature bursts is required, ideally in the reactor (although this may be difficult), otherwise preferably in the charge machine. One likely method which is at present being investigated utilizes the extreme reactivity between mercury and certain metals. A thin filament of one of these metals passes through the expansion chamber, the seal at the walls being made with a ceramic material which insulates the filament from the body of the container. A simple conductivity check on the integrity of the filament can be made at convenient periodic intervals, probably during fuel re-cycling operations.

Burn-up

The mercury will undergo continuous bombardment by thermal neutrons giving the following reaction:—

$$Hg^{199}+n \rightarrow Hg^{200}$$

The highly absorbing isotope Hg^{199} will thus be depleted with time and the efficiency of the device will drop. For the device described, the poison effect on firing drops from 2% to 1.5% over a period of three years (the average fuel lifetime).

For reactors fuelled with uranium oxide it is not convenient to locate the device within the fuel, because of the uncertainty of the centre uranium temperature under normal operating conditions. The device is best placed in the gas stream and, although the response to power surges is not now so rapid as in the case of a fuel-triggered device, it is still much more rapid than the response of the bulk of the moderator. If the reactor utilizes bundles of fuel rods then the expansion chamber can conveniently replace one rod of the bundle. The gas temperatures of these reactors are likely to be much higher than for Calder Hall-type reactors and it is probable that the triggering temperature will remain at about 650°C. The device would, therefore, resemble the previous description in most respects. The only change is likely to be in the choice of material for the expansion chamber, because niobium could not be exposed to the possible corrosive action of the cooling gases. Fortunately, however, the rod bundles tend to contain more fuel per unit length than the single Calder rods and the expansion chamber can be made of steel or iron-chrome alloys without seriously affecting the economics of the system.

Table 1. Mercury vapour pressure at various temperatures

Temperature °C	Vapour pressure (atmospheres)
550	14
600	23
650	35

Application to Small Research Reactors

So far we have concerned ourselves with power reactors, where fairly high triggering temperatures are desirable. For research reactors very low temperatures are utilized, and the choice of a suitable absorbing material is a difficult one.

However, one application which seems feasible is that of providing a safety fuse for a small polyethylene moderated reactor, to protect the moderator from temperature surges above 100°C. The device is illustrated in Fig 3. The absorbing material (1) is one of the more stable boron hydride compounds (e.g. B_4H_{10}, B_5H_9) which have boiling points well below 100°C. This is sealed in a plastic capsule (2) held in close contact with two sticks of polyethylene moderator (3). This particular design allows the absorber to discharge into ducts (4) so that the necessary increase in surface area is obtained with the minimum of voidage in the moderator. The speed of response to power surges can be increased by dispersing fuel within the polyethylene sticks.

The applications described above are those which are now being actively developed by the author's company. It is clear, however, that the phase-change device can be adapted to meet other circumstances. It has the advantage of being always inside the core and thus does not rely on any mechanical or electrical actuation.

Acknowledgements

The author is grateful to the Hawker Siddeley Nuclear Power Co., Ltd., for permission to publish this work. He would also like to thank Mr. M. Tennet for suggesting the filament integrity test for burst capsules.

(*Translations see page* 528)

Pressure Vessel Nozzle Design

A New Approach to Reinforcement

By R. T. ROSE, B.Sc., Ph.D.
(British Welding Research Association)

Hitherto, branch connections or nozzles on pressure vessels have always been provided with heavy reinforcement. This article reviews recent work on new methods of approach to the problem.

BRANCH connections for pressure vessels are still designed on the principles originally laid down for riveted construction, the fundamental principle being that the bursting pressure of a pierced drum should not be less than that of an unpierced drum of the same size and plate thickness.

This principle has always been simply interpreted. Considering a longitudinal section of the drum through the branch, it appears that the whole of the branch wall is needed to resist the hoop stresses, due to the pressure in the branch pipe, whilst there is a shortage of material in the drum where the opening is cut. Additional area must be provided to compensate for this shortage and this was done by the provision of a collar around the branch pipe, of cross-sectional area equal to that of the metal removed from the opening. Under these conditions and because of the ductile properties of boiler plate, the pierced but reinforced drum could be expected to sustain as high a pressure as the unpierced drum.

Long experience has shown this principle to give perfectly safe designs—in fact service failures of pressure vessels, attributable solely to poor design, are virtually unknown. Nowadays it is becoming essential to make economies in materials and fabrication, thus involving raising working stresses and designing wherever possible for a minimum of welding and reinforcement.

Over the past few years, the British Welding Research Association has devoted considerable attention to the design of branch connections for welded pressure vessels. Nozzles were selected for special attention because their stress-raising effect limits the working pressure of the drum to which they are attached. In the codes this limitation is provided by the adoption of a low design, or working, stress. In the absence of weaker portions of the vessel, a quantitative assessment of nozzle performance should permit, logically, an adjustment of design stress. Furthermore, the cost of nozzle fabrication makes worthwhile an investigation into the necessity for reinforcement and its most effective design.

Experimental Stress Analysis

Unreinforced branches were studied first, in order to provide a datum for assessment of the effectiveness of various types of reinforcement. The programme commenced[1] with the measurement of strains around an unreinforced branch of 12 in. bore and $\frac{3}{4}$ in. thickness welded into a drum of 42 in. bore and $1\frac{3}{8}$ in. thickness. The branch and drum had approximately the same diameter/thickness ratio, indicating that they were of similar pressure strength so that none of the branch wall could be deemed to compensate for the opening. The strengthening effect obtainable by the use of thicker branches (without compensating plates) was measured by fitting two further nozzles differing from the first only in thickness, this dimension being 1 in. and $1\frac{4}{8}$ in. respectively.

The test method was to apply electrical resistance strain gauges (of $\frac{7}{8}$ and $\frac{1}{2}$ in. gauge length) to inner and outer wall surfaces, spaced sufficiently closely at the regions of high stress to produce a continuous record of strain over the surface. The internal gauges had to be waterproofed by the method developed and described by Lane[2]. In later tests it was found quicker to use a small mechanical strain gauge for the outside readings.

These early tests provided a valuable insight into the behaviour of branch connections. It was found that the greatest stress was in the hoop direction, on the inside surface where drum and branch intersect, and occurred at the crotch. The convention used for defining a location round the intersection is shown in Fig. 1, where the crotch is defined as 90°. This hoop stress was nearly uniform

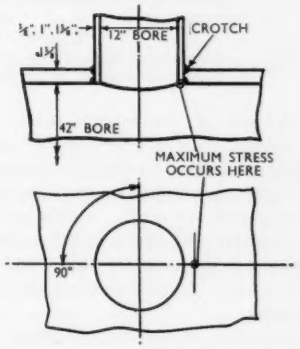


Fig. 1.—Unreinforced flush-finished nozzle, showing location of maximum stress.

through the wall-thickness and diminished rapidly at points further away from the opening, reaching a value equal to the undisturbed cylindrical shell stress in a distance of about 8 in. along the drum from the inner surface of the branch. The rate of decay at points along the branch was more rapid still.

Stress Concentration

Defining stress concentration factor (S.C.F.) as the ratio of the peak measured stress to the hoop stress in an unpierced drum of the same bore and thickness, at the same pressure, the S.C.F. for the thin unreinforced branch was found to be 4.0. In the thicker branches the factors were 3.0 and 2.6 respectively, although the maximum stress occurred at the same location.

The value of the S.C.F. for the thickest branch could not be considered excessive in designs employing the present low values of working stress. However, the extra thickness required does not make such designs attractive, nor do these results indicate that further additions to the branch thickness would yield significant decreases in peak stress.

This experimental work prompted the development of a theory[1], due to Wells, for adding a correction to the then current calculation methods, in order to arrive at an estimate of the peak stress at an unreinforced nozzle. Prior

to this development, the best known means of calculation was to treat the pressure vessel as a flat plate, loaded biaxially by stresses equal to the hoop and longitudinal drum stresses respectively, and fitted with a circular nozzle. Such methods gave a serious under-estimate of the true stresses and this was attributed to the absence of pressure

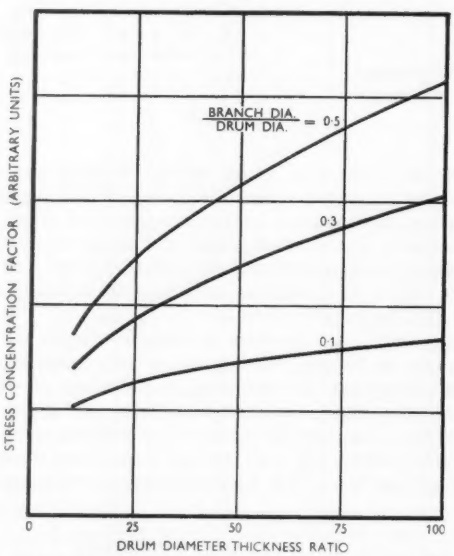


Fig. 2.—Variation of stress concentration factor at unreinforced flush-finished nozzles, as predicted by simple theory.

end-load on the branch in the flat-plate analogy. This end-load must be carried by bending action in the shell plate and, due to the curvature, gives rise to additional direct hoop stresses at the crotch. Using beam-on-elastic-foundation methods, these additional stresses could be calculated, and when added to the flat-plate stresses gave a value for peak stress which has been found to be in fair agreement, but greater than, the stresses measured on actual vessels.

Because of its approximate nature, this method of calculation is probably of greater use in research than in design, and therefore it is not given in detail here. However, it is of the greatest interest to see that the formulæ predict fairly large variations in S.C.F. as the geometry of the vessel is varied. These variations are shown in Fig. 2 where, to avoid any possibility of misinterpretation, the vertical scale is relative rather than absolute. A large increase in stress concentration factor occurs when the diameter/thickness ratio of the drum increases, and also when the ratio branch bore/drum bore increases.

Two conclusions may be drawn from this observation, concerning present design. First, if it is assumed that the purpose of reinforcement is to reduce peak elastic stresses (note that this is not a necessary implication of the original principle underlying reinforcement) then relatively more reinforcement is required on thinner or larger diameter vessels, and the possibility exists that at the other end of the range, very thick or small diameter vessels might not require reinforcement at all. This is not reflected in code design, which requires compensation to be proportioned to the material removed from the drum and this, for branches of the same bore, is the same as proportioning the collars to the drum thickness.

The second conclusion is that the need for reinforcement diminishes as the bore of the opening diminishes, a finding which is reflected in the code practice that usually permits single small holes to be uncompensated.

Reinforced Nozzles

Having obtained the stress distribution at unreinforced nozzles, it was decided to make a comparison with a nozzle reinforced according to code practice, and with other nozzles having reinforcement[3] disposed in different ways. The three plain nozzles were cut out of the 42 in. × 1⅝ in. drum and six others fitted. Five of these nozzles, shown in Fig. 3, were reinforced with a replacement of area slightly over 100%, and the sixth was not reinforced but instead was fitted to protrude slightly inside the vessel, a practice for which the elementary theory predicted favourable results. As before, the nozzles were made equal in pressure strength to the drum so that there could be no question of the branch proper providing reinforcement.

It will be appreciated that the branch, detail 1, Fig. 3, having a flat broad collar is the only one which accords fully with code requirements such as those of B.S.1500.

Using the same experimental techniques as before, the strains around each of the six branches were measured. The maximum stress concentration factors were found to

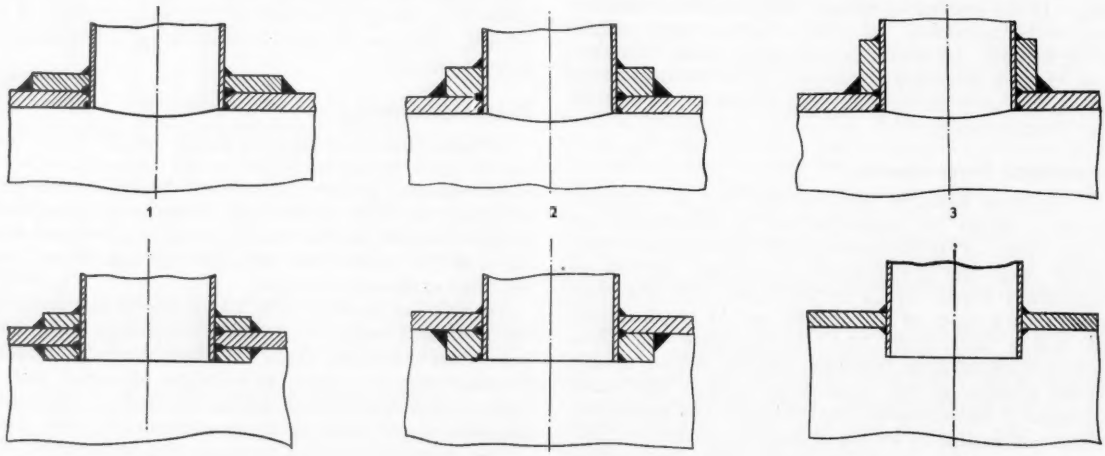


Fig. 3.—Nozzle design. Details 1 to 5 have 100 per cent replacement of area with reinforcement disposed in different ways. Detail 6, with no added reinforcement, performs better than Details 1, 2 and 3.

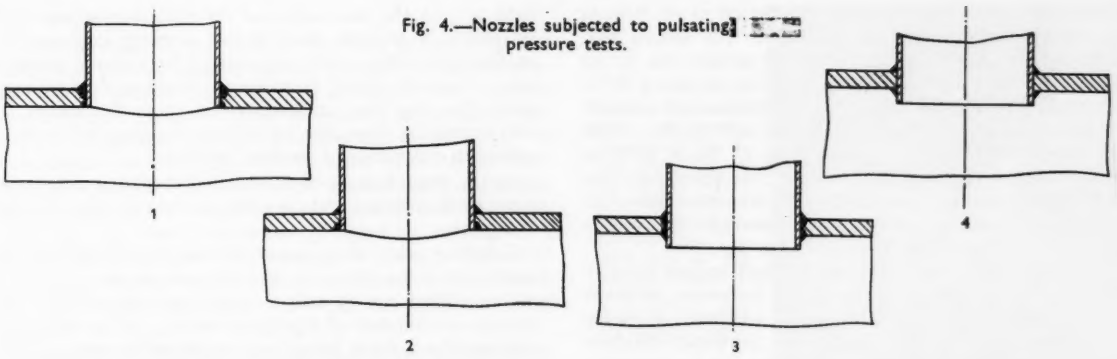


Fig. 4.—Nozzles subjected to pulsating pressure tests.

be 2.5 for the flat broad collar, 2.6 for the square section collar and 2.8 for the short tubular collar (details 1, 2 and 3 respectively). There is, therefore, very little change in measured maximum stress with change in width/thickness ratio of the reinforcement when its area is held constant, and the conventional broad collar has a slight advantage.

When the reinforcement is split equally between the inner and outer surfaces as in detail 4, a considerable reduction in stress is achieved. The greatest stress measured on this branch connection corresponded to an S.C.F. of 1.5. For detail 5, where the reinforcement is wholly inside the vessel, a lower stress is obtained than when the same reinforcement is applied externally. The measured S.C.F. was 1.9. The simple protruding tube design, detail 6, had a measured S.C.F. of 2.2.

Three main deductions may be drawn from these measurements:

(a) At branch connections designed to code requirements, stress concentrations at least as high as 2.5 may be expected.

(b) The disposition of external reinforcement is of little importance, and only symmetrically disposed (internal and external) reinforcement, with its added complexity, will significantly reduce the stress concentration.

(c) The simple protruding branch design is slightly more effective in reducing the maximum stress than the conventional reinforcing collar.

A further observation of interest was that in all the designs the hoop stress at the crotch was reduced from its value for an unreinforced branch but, with the exception

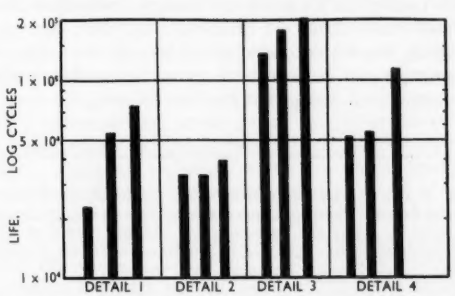


Fig. 5.—Number of pulsations of 100-2,000 lb/in² pressure withstood by nozzle details shown in Fig. 4.

of detail 4, still remained the maximum stress. In the case of detail 4, the maximum stress was transferred to the 0° position, acting at the drum inner surface adjacent to the fillet welds, and radially to the branch. This stress was non-uniform through the wall thickness, illustrating the presence of a bending moment, a danger known to exist at over-massive reinforcements. For the completely unreinforced hole, the greatest stresses are in the hoop direction in the bore of the hole, whilst the stresses radial to the hole are negligible. Addition of reinforcing material causes a diminution of the hoop stresses accompanied by an increase in the radial stresses which transmit load from the shell to the reinforcement. Eventually a point is reached where the radial stresses are the greatest in the structure and appreciably above the level of the nominal stress. Such a nozzle design was tested and reported[4] by Schoessow and Brooks and, with a replacement factor of 302% exhibited radial stress at the edge of the reinforcement of a magnitude 1.51 times the nominal stress, whilst the hoop stress at the bore of the nozzle had a magnitude in the same terms of only 1.05.

Pulsating Pressure Tests

Fatigue failure receives no direct attention in the various pressure vessel codes, and such failure is rare in service. But in any move to raise working stresses it is important to know at what stage the possibility of fatigue failure presents a real danger. In fact in their paper[5], Carlson and McKean suggest that when more is known, a fatigue criterion should be used for the design calculations.

Fatigue testing was commenced, therefore, to provide basic data on the fatigue resistance of vessels to the stress concentrations at branch connections, and also to provide a comparative assessment of various nozzle designs.

For pulsating pressure tests of nozzle designs[6], drums of 20 in. bore and 1 in. thickness were used, each fitted with a single branch connection of $6\frac{7}{8}$ in. bore and $\frac{1}{8}$ in. thickness. The drumheads were of 2 : 1 semi-ellipsoidal form of 1 in. thickness, welded to the drum by the submerged arc process, and giving the vessels an overall length of about 42 in. The branches were closed by means of hemispherical caps of $\frac{1}{8}$ in. thickness, into which were welded the pressure supply pipes.

The nozzle types chosen for test were unreinforced set-in branches, finished flush at the drum inner surface, and unreinforced branches protruding slightly into the interior of the drum. For each of these two basic designs two types of weld detail were tested. These could be described broadly as partial penetration welds and fully interpenetrating welds. The four distinct designs are shown in Fig. 4. Once again, the branch pipes were of equal diameter/thickness ratio to the drums. The branch connections were manually welded using electrodes to B.S.1719 (Class E, 317), which were dried before use. The completed vessels were stress-relieved at 600°C. Three specimens of each design were tested[7] by repeated applications of pressure, using a special hydraulic plant, each pressure cycle rising from 100 to 2,000 lb/in.². The fluid used was

water with a small proportion of soluble oil to act both as a lubricant and a corrosion inhibitor. No special precautions were taken to ensure a constant temperature during the test, but this soon reached equilibrium at about 30°C. The rate of testing was about one application of pressure per second, and the test was continued until failure. This was always manifested by a fine spray of liquid escaping from a crack at the branch connection; the vessel was then taken off test and the number of cycles was recorded. The results for all twelve specimens are shown in the column graph with a logarithmic life scale (Fig. 5).

After test each nozzle was cut out and broken open to reveal the fatigue crack, and a typical failure is shown in Fig. 6. This typical failure lies in the longitudinal section plane, through the nozzle, and spreads outwards from the inner surface, eventually causing leakage. It is important to notice that the typical crack does not originate at the root of the weld, even when partial-penetration welds are employed. That the fatigue failure should occur elsewhere and should ignore the severe notch effect at the weld root can be explained by the aid of the earlier stress-analysis work. This showed clearly that the greatest stresses at unreinforced branches were the hoop stresses at the bore of the branch, occurring at the crotch. The radial stresses at this type of connection were negligible. The notch effect of the weld root would achieve its greatest effect as a stress raiser on these radial stresses whilst having little influence on the hoop stresses. The result indicates that the combination of notch effect and small radial stress is not the most important in the structure.

The average life for each design was 51×10^3 cycles and 36×10^3 cycles for the flush-finished branches having full and partial-penetration welds respectively, and the corresponding figures for the protruding branches were 173×10^3 and 73×10^3 cycles respectively. The nominal hoop stress range in each pressure cycle was:—

$$pD/2T = (2000 - 100) \times 21/2 \times 1 = 20{,}000 \text{ lb/in.}^2$$

This is 38% greater than the design stress of 14,500 lb/in.^{2} laid down by B.S. 1500 for steel of 26 ton/in.^{2} U.T.S. such as that from which the drums were made.

Application to Design

In order to assess the significance of these results it is necessary to determine to what extent the test conditions approximate to service conditions. Obviously, the number of cycles of full pressure applied to a vessel during its working life will vary widely with the type of duty. As an example, a vessel shut down overnight would experience 7,300 cycles of full pressure in a working life of 20 years. Power boilers would experience a smaller number of cycles as also would most chemical process vessels working a batch process. Additional to these full-pressure applications are, on the one hand, the far more numerous, small pulsations of pressure that normal working imposes and, on the other, the initial and routine hydrostatic pressure tests. The very few hydrostatic tests have no direct fatigue result, but, by the introduction of residual stresses, the over-pressuring may alter the fatigue resistance to the more numerous pulsations of working pressure.

Again, the influence of the small fluctuations of pressure is not easily assessed and no doubt would vary with the type of service.

A further point of variation between the service and test conditions is the rate of application of the pressure. The test conditions can be seen to differ from the service conditions in a number of significant ways, and therefore it is necessary to apply a fairly large factor when using fatigue test results of this sort for design purposes. A factor of 10 on the number of cycles to failure is a figure commonly proposed in America. Even with this factor certain other conditions must be satisfied. There must be no danger of corrosion fatigue, since this phenomenon could drastically reduce the performance of a vessel, and also the working temperature of the vessel must be considered. A relatively small increase in temperature would not appreciably affect the fatigue resistance, although at temperatures where creep is significant it might.

Adopting the factor of 10, the pulsating pressure tests show that unreinforced nozzles have a resistance to fatigue failure adequate for many applications, and for these cases the reinforcement demanded by the codes is unnecessary. However, the variation in S.C.F. with drum diameter/thickness ratio, shown in Fig. 2, suggests that, for larger values of the ratio, shorter fatigue lives should be expected. It is not possible to generalize the reinforcement requirements, therefore, and further testing would be helpful. It must also be remembered that, in the instances where cyclic external loads are applied to nozzles by attached pipe work, it may be necessary to consider the reduction in fatigue life due to the superimposition of stresses.

The test results demonstrate the considerable fatigue resistance of mild steel to the stress concentrations at unreinforced nozzles, and suggest that if, by the use of reinforcement, the stress-raising effect may be mitigated, a considerable increase in design stress should be possible. Nevertheless, the efficacy of this reinforcement must be proved in fatigue tests, and the British Welding Research Association is now carrying out an extensive programme of such testing on a variety of branch connection designs. A preliminary result of this work is that the simple, protruding, branch design, attached by means of fillet welds, is of nearly equal performance to the best collar-reinforced connections, and is superior to current designs.

Tuyères pour Récipients sous Pression

Lorsque l'enveloppe d'un récipient sous pression est perforée pour le passage de tuyères ou de tubulures, on considère toujours comme obligatoire d'ajouter un équivalent de renforcement pour le métal qui a été enlevé. L'article décrit des travaux effectués par l'Association Britannique de Recherches de la Soudure, qui semble montrer que des résultats améliorés peuvent être obtenus sans un tel renforcement, le besoin en diminuant à mesure que le rapport du diamètre à l'épaisseur de tant le récipient que la tubulure diminue. Les travaux continuent.

Düsen an Hochdruckkesseln

Wenn der Mantel eines Hochdruckkessels für Düsen oder Abzweigungen an mehreren Stellen durchbrochen wird, wird es immer für absolut notwendig gehalten, Verstärkungen anzubringen, die der Menge des Metalls, das entfernt worden ist, entsprechen. Der Aufsatz berichtet über Untersuchungen, die von der British Welding Research Ass. ausgeführt sind, und die anscheinend zeigen, das bessere Ergebnisse ohne solche Verstärkungen erzielt werden können, wobei die Notwendigkeit sich im Verhältnis von Durchmesser zur Stärke von Kessel sowohl als auch Abzweigung verringert. Die Arbeiten sind noch nicht beendet.

Boquillas en Recipientes a Presión

Cuando el casco de cualquier recipiente a presión es perforado por boquillas o derivaciones, se ha considerado siempre obligatorio agregar un refuerzo equivalente a la porción de metal que se haya extraído. En este artículo se describe la labor realizada por la British Welding Research Association (Asociación Británica de Investigación en Soldadura), que parece demostrar que pueden conseguirse mejores resultados sin la aplicación de tales refuerzos, disminuyendo su necesidad conforme se reduce la relación del diámetro al espesor del recipiente y la derivación. Se continúa la investigación sobre este punto.

U.S. Investigations

The emphasis in this fatigue approach has been to test complete pressure vessels, each as closely representative as possible of present manufacturing practice. The work of the American Pressure Vessel Research Committee of the Welding Research Council on high strain fatigue[8] may be considered complementary in approach in so far as there the emphasis has been placed on the testing of materials. In this approach, results could be obtained relatively cheaply from small specimens designed to develop 2 : 1 biaxial stress fields over a critical area. The 2 : 1 ratio of the biaxial stresses was chosen to simulate the ratio of hoop to longitudinal stresses present in an unpierced thin cylinder.

Two types of specimen were used, one a cantilever beam profiled to produce the required stress conditions, the other a rectangular, flat plate simply supported and loaded by pulsating pressure on one side. Besides investigating the effect of heat-treatment, surface condition and machined notches, the test programme covered a variety of steels ranging from 55,000 lb/in.^{2} to 195,000 lb/in.^{2} U.T.S. As the investigation was aimed at pressure vessel design, the number of cycles to failure was limited to the order of 10^5 rather than the usual 10^6 or 10^7 cycles required for machine parts. For these relatively low lives the stresses applied were greater than the yield point and it was convenient to obtain the results in terms of strain rather than stress. By conducting the tests on the cantilever specimens at constant deflection, the surface fibres of the beam could be forced through any plastic strain cycle required, and complete fracture was taken as the failure point. In the case of the plate specimens, a permanent set developed at the higher pressures, since pressure was applied to only one side. Under these conditions, the strain range that could be applied repeatedly was limited to that at which the full plate thickness was rendered plastic. The point of failure was taken as the number of cycles at which a crack $\frac{1}{16}$ in. long appeared in the plate surface.

The similarity between the plastic strain cycling of the specimens and the highly stressed material at discontinuities in pressure vessels is self evident. In a pressure vessel it is a cardinal rule of design that no section of the plate material should be fully plastic under pressure loading, since this would at the least cause excessive deformation, and might result in failure. Consequently it may be assumed that the small volumes of material experiencing stresses greater than the yield point, and in which fatigue failure would originate, are surrounded by much larger volumes of supporting material at a stress level still within the limit of elasticity. As a result, on the release of pressure the yielded material is forced into residual stress by reason of the maintenance of the original vessel geometry. In this way, a concentrated stress range of approximately twice the yield point in magnitude is accommodated without causing repeated yielding, whilst in more severe cases repeated yield and reverse yield ensue.

The results of these tests showed that the strain range to cause failure at 10^5 cycles was approximately proportional to the ultimate tensile strength of the steel, whilst for lower lives there was less spread between the permissible strain ranges. For lives of the order of $5\text{-}10 \times 10^3$ cycles the interesting result was obtained that the strain range was nearly the same for all steels, and the mild steel (ASTM A 201) performed better than some of the stronger materials. Of course, the stress range corresponding to this nearly constant strain range would vary with the strength of the steel, but the probability is that such excessively high strains as these would be induced not by pressure loading but by an applied deflection, as in the case of thermal expansion of a pipe system for a special application where cycles were few. The lower stress for the mild steel would be an advantage because it would reduce the pipe system anchor thrusts.

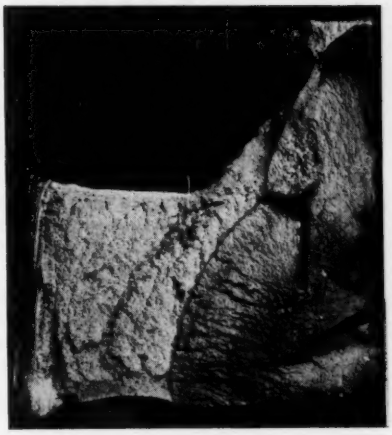


Fig. 6.—Typical fatigue crack at crotch of nozzle, Detail 1 of Fig. 4. The dark area is the fatigue crack, bounded characteristically by circular markings. The light area is the fracture made in breaking open the specimen to reveal the fatigue crack.

A ratio of nearly 2 to 1 was found between the resulting strain range for a given material, obtained with the cantilever and plate specimens respectively. The difference was attributed to the fact that the cantilever specimens were polished, whereas the plate specimens had the mill scale left on the surface. Further, the difference between the failure criteria (i.e. full fracture and $\frac{1}{16}$ in. crack) would have contributed to the difference.

The tentative proposal by Kooistra[8] to apply these results to vessel design is interesting. Using the strain range determined by the cantilever specimens for a life of 10^5 cycles, and adopting a strain raising factor of 4 to cover all discontinuities and flaws, he calculates a permissible design stress for each material. This is found to be 22,000 lb/in.^{2} for ASTM A 201A or 61% of the yield point and 37% of the U.T.S. For the stronger steels the design stress is generally a slightly smaller percentage of the U.T.S.

This approach to design is such that a diminution of the stress concentrations at discontinuities leads to an increase in permissible design stress. This would be an admirable feature of a code, enabling the designer to achieve economies in drum thickness by careful detail design, or to use a somewhat thicker drum with unreinforced branch connections where this appeared advantageous. The upper limit of design stress that may be achieved by the use of connections, drumheads and so on, of low stress concentration factor is, of course, the yield point of the steel, since this represents the absolute limit of design stress which might be approached but never reached. Assuming that the only type of stress concentration present were the extremely local kind (this rules out stresses due to non-circularity which may be of a widespread nature and result in full plasticity across a section) and that creep and corrosion could be discounted, the stress (or strain) concentration factor could not exceed 2.5 for a design stress of 100% yield point magnitude. This implies that there is no possible advantage to be gained by a reduction in the S.C.F. below 2.5.

Comparison of British and U.S. Results

Before this figure is compared with the S.C.F. determined by strain gauge tests on various branch connections, it is necessary to be clear on its meaning. A comparison between the performance of the B.W.R.A. pulsating pressure test vessels and the American test specimens will be helpful. The protruding branch design with full

penetration welds had an average life of 173×10^3 cycles at a nominal stress range of 20,000 lb/in.^{2} The measured S.C.F. for this design was 2.2, so that the concentrated stress range was 44,000 lb/in.^{2}, and taking Young's modulus as 30×10^6 lb/in.^{2}, this would equal a strain range of 0.147%. For steel of 26 tons/in.^{2} U.T.S. (ASTM A.201A), Kooistra[8] gives a value of about 0.27% strain range as measured on the cantilever specimens, for the same number of cycles. The discrepancy is of the same order as that between the results obtained on the plate and cantilever specimens, and no doubt much of the difference must be attributed to surface condition. This indicates that a sizeable factor must be used in conjunction with strain-gauge results when assessing the true strain-raising factor. Special caution would be necessary when there was reason to suspect that the greatest stress was at a point inaccessible to strain gauges.

The application of the fatigue results obtained on specimens stressed biaxially, to all types of stress concentration occurring in pressure vessels might be criticized. It is known that the stress concentration at a nozzle is more akin to a uniaxial than a biaxial stress system, and although little is recorded on the subject it is probable that uniaxial stressing is most severe. The presence of the stress gradient in the specimens, both of which suffered bending, is a further source of uncertainty. The gradient exerts some influence on the effectiveness of a stress concentration, and is considered by some authorities to be responsible for the size effect in fatigue testing. Again, little is known, and until more information is available these secondary effects must be allowed for by generous safety factors. The advantages of testing pressure vessels rather than specimens are self-evident, and must be added to those of testing actual welded details rather than welded specimens.

It is now well known that the limits of size, pressure and temperature for which vessels of mild steel can be made satisfactorily have been reached. Both the weight and the thickness of mild steel drums for these advanced applications are excessive and, besides the difficulty of maintaining the metallurgical qualities of thick plate, the welding of the drums, the treatment of excessive thermal stresses and the design of supporting structures, all present additional technical and economic problems. The search for a stronger steel has not produced a material having a ratio of yield strength to U.T.S. as low as that of mild steel. Stronger steels invariably have a high value of this ratio, and the gain in strength is such that the application of these steels to pressure vessel construction would not be attractive if a factor of 4 were used, as at present, to calculate the design stress from the U.T.S.

Whilst a full discussion of this problem is outside the scope of this article, it is apparent from the American results that a fatigue criterion of design would be tantamount to the use of the factored U.T.S. as the design stress. However, these same results, and the proposal by Kooistra, indicate that there might be an advantage in using the stronger steels if the stress concentration factors could be reduced. It appears within the bounds of possibility to reduce the tentatively suggested factor of 4 to one of 3, and even lower factors should be obtainable if elliptical rather than circular branches[4] were used.

Conclusions

In conclusion, it will be apparent to those who are actively engaged on pressure vessel design that the present method which permits the calculation of a basic thickness using a fictitious stress is an over-simplification that cannot be accepted today. The alternative is a rational design method such as that outlined by Carlson and McKean[5] in reply to discussion, in which the actual stresses, including the stress concentrations, are given consideration for each part of the vessel, and in which the consequences of the action of these stresses on the material of the vessel must be considered separately. Such a new approach would throw a fresh burden of responsibility on designers who could no longer take advantage of a large, blanketing "safety factor," and many fresh problems would present themselves. These problems are already being met by the designers of nuclear power reactor pressure vessels for the design of which no code makes provision, and for which no experience is available.

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Translations for "Ultimate Safety Device for Thermal Reactors" (Page 521)

Nouveau Dispositif de Sécurité pour Réacteurs Nucléaires

On propose un dispositif de sécurité qui est indépendant des mécanismes mécaniques ou électriques, et qui fonctionne, dans le cas des pointes de courant, par l'augmentation de la température du combustible. Le dispositif se sert de l'augmentation considérable de la pression de la vapeur de mercure lorsque les températures s'élèvent.

Chaque élément combustible est creux et contient une quantité de mercure contenue dans un espace restreint par une capsule dont l'éclatement se produira à la température appropriée en permettant à la vapeur de se dilater et de remplir l'élément combustible creux, en faisant arrêter ainsi le réacteur par l'augmentation considérable de l'absorption des neutrons.

Eine neue Sicherheits-Vorrichtung für Kern-Reaktoren

Es wird eine Sicherheits-Vorrichtung vorgeschlagen, die von mechanischen oder elektrischen Mechanismen unabhängig ist, und die anspricht, wenn ein plötzlicher Kraftanstieg erfolgt durch ein Ansteigen der Brennstoff Temperatur. Die Vorrichtung benutzt den starken Anstieg des Dampfdruckes von Quecksilber bei steigender Temperatur.

Jedes Brennstoffelement ist hohl und hat im Inneren eine Kapsel, in der sich eine Menge Quecksilber befindet. Bei einer bestimmten Temperatur bricht die Kapsel, und der Dampf expandiert und füllt das hohle Brennstoffelement, sodass der Reaktor durch die dann stark gesteigerte Absorption von Neutronen abgestellt wird.

Nuevo Dispositivo de Seguridad para Reactores Nucleares

Se propone un dispositivo de seguridad, el que es independiente de los demás aparatos mecánicos o eléctricos y que opera, en el caso de sobrecargas de potencia, por medio del aumento de temperatura del combustible. Este dispositivo se vale en gran medida del considerable aumento en la presión del vapor de mercurio con el aumento de temperatura.

Cada elemento de combustible es hueco y contiene cierta cantidad de mercurio confinado en un pequeño espacio por medio de una cápsula que revienta a la temperatura apropiada y permite que el vapor se dilate y se llene el elemento hueco de combustible, haciendo parar de esta forma el reactor por el gran aumento en la absorción de neutrones.

Unclear Times

EARLY XMAS

PUBLISHED FOR XMAS AGAINST OUR BETTER JUDGMENT

RETREAT FROM GENEVA

BRITAIN'S ECLIPSE

"Giant Atom-smasher Our Only Chance"

BACK from Geneva, with bowed heads and dragging footsteps, bewitched, bothered, bewildered, fed up, and far from home, come the ex-White Hopes of Britain, the atom men. I see an army in retreat, its uniforms gone, its colours abandoned, its drums and music silenced. It is defeat.

As I stand in this historic building at London Airport, seeing them as in a dream, shorn of their white coats, their film badges, and even the background of gleaming laboratories, test-tubes, long tongs and glove boxes so familiar to us all from their publicity pictures, it is difficult to realize that this sorry rabble, shuffling shamefacedly through the Customs, is the same glorious army that set out, with gallant hearts and bulging wallets, on their historic crusade to blazon forth to the world, Britain's achievements in the atomic field. . . . It is defeat.

Not enough Mice

"Yes," said a weary scientist, "it certainly was a shambles. We are just not in the picture. . . . Other nations are ahead of us in every field that matters. We are thirty-three, *thirty-three* mark you! generations behind in the effect of irradiation on the heredity of the fruit-fly, and America has some 10^4 or 10^5 more mice under investigation than we have been able to breed—let alone irradiate. We have produced no new elements with half-lives too short to be measured in quantities too small to be seen. We have not discovered—even in theory—any new atomic particles. Worse still, we aren't really sure if any more *need* inventing.

"All we have to show," he went on, with the bitter laugh of a soul in torment, "are a couple of measly power stations, and four more under construction . . . just beastly practical things that *work*! . . ."

Blueprint for Success

"There is just one hope—and only one" he continued. "We *must* have the largest accelerator in the world NOW! Fortunately, a scheme has been worked out, and only needs putting into operation to restore our national prestige. London's Underground railway is to be taken over immediately. The Inner Circle will make a reasonably good cyclotron, after a few corners have been straightened out. . . . The West London Air Terminal building will do for a good control room, because it's not very near any of the stations. The Central London tube from Liverpool Street to White City will make a linear accelerator, after we've polished off the ribs inside the tube." . . . He sighed. . . . "It'll cost a few million pounds—or megaquids to use the scientific term, and probably inconvenience the travelling public, but it's worth it to save us from the awful stigma of being just a . . . just a . . ." his voice faltered . . . "a Commercial Success. . . . It doesn't bear thinking of." . . . He broke down, and a kindly colleague led him away, sobbing.

"Britain in Chains," by Lord Heaverbrick. Page SEVEN.

SLOSH—The Stuff for Washday Glamour!

SLOSH Will give you Zero Gamma!

GENEVA EXHIBITION FAKE EXPOSED!

All Cardboard!

By "U.T." Special Reporter

THE impressive show made by Britain's so-called atomic industry at Geneva was, in reality, part of a vast Government propaganda scheme it was revealed to-day in well-informed—and ever-decreasing—circles. After a search through three separate continents (and two mixed ones) the *Unclear Times* is able to reveal the best-kept secret of all, that the ranks of imposing-looking stands at the Commercial exhibition advertised companies that *do not exist*!

All the stands were made of cardboard—as were most of the exhibits themselves. The so-called "engineers" and "salesmen" lending an air of brisk efficiency to this staggering deception were, in reality, out-of-work actors and television producers. Bonk Mobhouse and Guinness Deadpan wrote the script, and the entire production was by Little Princer (by permission of Winnie Morrick).

"I Was a Gun Girl for the A.E.A." . . . Amazing disclosures of the zirconium-smuggling racket! Page SIX

IS YOUR FACE *SPOTTY?*

Hair falling out?

Bones getting brittle?

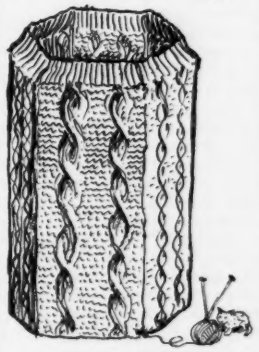
Nausea and giddiness?

YOU SHOULD HAVE USED

THICKA

CONCRETE SHIELDING

Knit this gay
Reactor-Cosy!



Free Pattern Inside!

DR. FINAGLE

His Life— And Glad of it!

ALOYSIUS PLANTAGENET FINAGLE was born at an early age to parents of the type usually known as "sound yeoman stock," not to be confused with the ordinary stock used for making soups.

His early childhood was uneventful, except for the usual childhood ailments—broken neck, ringworm, leprosy, delirium tremens, and premature baldness. At school his performance was a little short of that expected; he

A. P. Finagle with the original vertical bread-and-butter launching machine.

eventually passed the eleven plus examination at the age of 23.

Formative Years

Leaving school he turned his attention to the scientific life. Early observation of the movements of a kettle lid gave rise to the idea of utilizing the power of steam and his design progressed as far as the separate condenser before discovering that his patents had been anticipated.

Inspired by Einstein's work he wrote a considerable amount of blank verse before realizing that he had one of Gertrude Stein's books by mistake. Returning to the original work which eventually made Epstein famous, his imagination was fired by the power obtainable from atomic fission, until he discovered that he was working in the wrong units.

Floating a company called Finagles Atomic Energy Autocracy he later sold out to the A.E.A. when the word "Finagle" was dropped from the title.

It was during his early years with experimental reactors that, following a loud report and a certain amount of alteration to the surrounding landscape, he gave vent to the famous saying (often wrongly attributed to Disraeli) "It is easier to be critical than correct."

First Law

The piece of work for which Dr. Finagle is best known, however, is his Law of Maximum Inconvenience (closely related to his work on the Inherent Maliciousness of Inanimate Objects). Finagle's Law of Maximum Inconvenience states:—

> "When an event can occur in more than one manner, it invariably occurs in that manner which causes the maximum inconvenience to the observer."

It may be of interest to report briefly, as far as security restrictions will allow, on the brilliant series of experiments which led Dr. Finagle to discover this result.

The experiment consisted of propelling a large number of slices of buttered bread into the air and determining the Finagle fraction F, defined as follows:—

F=Number of slices landing buttered side down/Total number of slices launched.

Considerable difficulty was experienced in finding a suitable method of launching the bread into the air in a regular manner. However, the following method was found to be satisfactory.

A wooden wheel 5.98 cm thick and 95.54 cm in diameter was fitted with a number of radial steel spikes, of root diameter 2.27 cm tapering to a point at 13.37 cm. A surface finish of 1 micron was achieved. The wheel was mounted with its axis vertical, and could be rotated by means of a belt drive from an electric motor controlled from an observation chamber 40 yards away.

The bread was carefully prepared according to a set of standard dimensions, was buttered on one side, and alternate slices were mounted on the spikes facing inwards and outwards. When all the bread had become detached from the wheel, the motor was stopped and a count taken.

In later experiments, the thickness of the butter was varied and it was confirmed that, the thicker the butter, the nearer the fraction F approached to unity. The effect of spreading jam on the butter was also investigated, the factor Fj being obtained.

It was found that Fj could be calculated from the following formula (due to Potter, Ab.).

$$F_j = \tfrac{1}{2}\left\{(1 - e^{-at})(1 - e^{-bs}) + 1\right\}$$

where t=thickness of jam in cms s=cost of jam in shillings per lb. a and b are constants.

If s is given in dollars/lb., the constant b should be multiplied by the conversion factor:

Gigaquids/Megabucks $\times 10^{-3}$

Dr. Finagle is at present working on a new correlation of results which, it is hoped, will explain the anomalous behaviour of quince jelly.

Been exposed to Fall-out, Tosh?

Decontaminate with SLOSH!

Cleaner, sweeter, nicer, neater,

Is a wash that's free from Beta!

Scientific Integrity

CHRISTMAS PARTY GAMES

STOCKPILING

A good game suitable for any number of players, each of whom should be provided with a small piece (approx. 500 g) plutonium. The players sit around in a circle, the object of the game being to pile the plutonium up into a heap, each player using his piece in such a way that while he himself does not achieve criticality, the next player does.

The first player to notice a blue glow and to leg it for the tall timber is the winner.

"PRESSPICS"

This game is played between two sides. A number of players represent different A.E.A. Establishments, such as Headquarters, Windscale, Risley, Harwell, etc. Each of these players is issued with 10,000 photographs all randomly numbered, which they must keep face down so that only the number and not the photograph is showing, with the exception of Headquarters, who have the pictures in full view.

The remaining players represent the Press, and the object of the game is to demand photographs which Headquarters have not got and which they in turn must obtain from one of the other establishments. Since Headquarters do not know the number of the picture and the other establishments will only deliver the picture if the correct number is quoted, some very amusing situations arise.

The player who first shoots the player representing either Risley or Harwell is the winner.

UNSOUND APPROXIMATIONS

". . . The correction in the case of soft tissue is only about 10% and, for most practical purposes, the röntgen, the rep and the rad can be regarded as numerically equal."
Barnes and Taylor,
"Radiation Hazards and Protection."

The RONTGEN now equals the RAD and the REP
And, presumably (sometimes), the REM;
This simplification's a very fine step,
A truly remarkable stem.
Too often the RONTGEN'S confused with the RAD
Or even the REM or the REP
But now, we can truthfully claim to be had
(The Americans say "getting hep").

Now, Taylor and Barnes are not just spinning yarns
When they co-relate REMS, REPS and RADS
And are really sincere as they make matters clear
For less talented lems, leps, or lads;
And before we employ such a neat stratagem
(Or should it appear stratagad?)
They warn us we might be a bit to the bem
Some ten per cent (max) to the bad.

Yet when things seem so plain, 't would be shame to remain
Of our simplification despoiled
For, in the last issue, we're mostly soft tissue
(Though Tangent is fairly hard-boiled)
And when all's said and done, it is only Point One
To subtract—or to emm, epp or add,
REM, REP, RAD or RONTGEN, I'm möntgen, by Göntgen,
By Gad, sir! It's driving me MAD!

HE LOVES YOUR HANDS—

because he knows they're SAFE

—if you use a

BOLLARD

Personnel Monitor

DECLASSIFIED ADVERTISEMENTS

FOR SALE. Twelve air blowers, each approximately 250,000 cu. ft./min. Suitable for ventilating grievances, or would sell separately as hair-dryers. Apply Box XXX, care of "Unclear Times."

FOR SALE. Noble Pile in well-fenced grounds situate on quiet Cumberland coast. Eminently suitable Mental Institution or Osteopathic and Remote Manipulation Sanatorium. Easy reach of power station, etc. Few hours' walk shops and buses. Details from Right Krank and Nutty.

FOR RADIANT HEALTH come to Gutlings new Winfrith Holiday Camp. You'll be right in your element! Also Fun Fair, including Tunnel of Love, Electronic Amusement Arcade, etc. **ALL THIS SEASON.** Special engagement of the Fasting Scientist in the Lead Coffin.

Unclear Times

DATA SHEET*

No. 0. Noelium

Symbol	
Atomic weight	25
Abundance	1/365

PHYSICAL PROPERTIES

Crystal Structure	Double Diamond
Absorption	Indeterminate (large)

Resistivity

At Room temperature	1 Scrooge
At Bar temperature	nil

COMPATIBILITY

Liquids—Readily absorbs all alcoholic compounds and mixtures with varying effects on physical properties. Inert to water. Reacts with bismuth.

Fig. 1.—Diagram of crystal structure (scale in Angostura units).

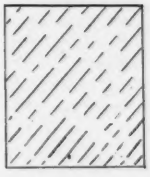


Fig. 4.—Mancunian interpretation of Noelium.

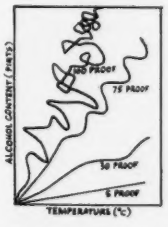


Fig. 2.—Effect of alcohol on stability.

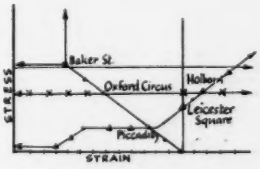


Fig. 5.—Mechanical properties of tube.

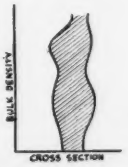


Fig. 3.—co-relation of thermal expansion, pressure and compatibility, derived from vital statistics.

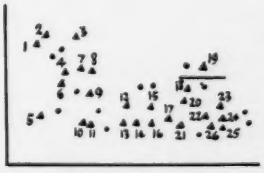


Fig. 6.—Co-ordination of Figs. 2-5, joining the relevant numbers in ascending order gives an important Noelium characteristic.

* *Specially compiled for the "Unclear Times" by J. Bellerfry-Battes, Mus.Bac. (Ox.), Senior Metallurgist, Egg Marketing Board.*

ROAD TESTS OF NEW REACTORS

1. The X—MAS

By "Control Rod"

WE were recently privileged to have on test the latest version of this exciting research reactor. In keeping with current trends, the design owes much to the Italian Fermi, although, of course, the model is entirely British-made. This year a number of important changes have been made: a much finer aggregate is now used in the concrete shielding, the suspension of the control rods has been improved, and the control panel is now fitted with new blue knobs which are more sympathetic to operator "feel" than the old white ones.

Performance is truly remarkable. From start-up (using a conventional neutron source in preference to the old acid type of accumulator) to full power takes just over the millimicrosecond. Under good conditions, with an experienced operator this timing can be considerably improved. Fortunately tyre wear is negligible.

To drive the X-MAS is a refreshing experience. Although it is a comparatively inexpensive vehicle (the cost is something in the region of £1,000,000), it has, of course, fully automatic control. In many respects X-MAS is foolproof, although the makers have taken every precaution. The model tested was equipped with a SCRAM signal equipment which can be supplied as an extra.

Standard equipment includes a built-in swimming pool, water being included in the purchase price. As previously mentioned, a finer aggregate is now used in the concrete shielding wall. The much smoother exterior thus obtained has enabled the makers to dispense with the need for an undercoat. It remains to be seen whether the new finish will be adversely affected by tropical conditions.

Turning now to actual operation, perhaps the most noticeable feature is the extreme quietness of operation. Indeed, apart from the indication of the instrument panel, the only external evidence of the mighty power of the engine is a faint blue glow. At a time when fuel economy is of the utmost importance it is refreshing to note that one charge will last X-MAS until June (or alternatively June to Xmas, of course). A premier grade of U235 is strongly recommended: applications for supplies should be made at your nearest A.E.A. filling station.

Just a very small amount

Brings you down to Background Count!

ATOMS AND THE CLASSICS

Winfrith Heath
. . . Farewell happy fields
Where joy forever dwells, hail, horrors, hail! — Paradise Lost

. . . Anon out of the earth, a fabric huge
Rose, like an exhalation. — Paradise Lost

HEPO
How reverend is the face of this tall pile! — Congreve

Zero Energy Reactor
. . . For I am nothing if not critical. — Othello

Commissioning Calder
. . . Find out the cause of this effect
Or rather say, the cause of this defect
For this effect defective comes by cause. . . . — Hamlet

All is gas and gaiters. — Nicholas Nickleby

Road Transport
How far is it, my lord, to Berkley now? — Richard II

Dounreay
. . . The cloud-capp'd towers, the gorgeous palaces,
The solemn temples, the great globe itself . . . — The Tempest

Windscale
. . . where glory's faded smile
Sheds lingering light o'er many a mouldering pile. . . — Felicia Hemans

Remove not the ancient landmark. — Proverbs

Criticality Alarm
. . . Who's that which rings the bell? Diablo, ho!
The town will rise; God's will, lieutenant, hold,
You will be shamed for ever. . . — Othello

. . . Silence that dreadful bell! it frights the isle
From her propriety: What is the matter, masters? . . . — Othello

Cooling Circuits
It is quite a three-pipe problem. — Sherlock Holmes

Plutonium Stockpile
Infinite riches in a little room. — Marlowe

Now cheaply bought—for thrice their weight in gold. — John Ferrier

Fuel Element Assembly
. . . O, your only jig maker. . . — Hamlet

. . . If it be made of penetrable stuff
If damned custom have not braz'd it so. . . — Hamlet

Control
. . . His rod revers'd
And backward mutters of dissevering power. . . — Comus

. . . I am too high born to be propertied;
To be a secondary at control. . . — Richard II

Canteen
'Tis merry in hall
Where beards wag all. — Thomas Tusser

Metallurgy
. . . like some ore
Among a mineral of metals base
Shows itself pure. . . — Hamlet

D_2O Leak
. . . What precious drops are those?
Which silently each other's track pursue. . . — Dryden

Research
Attempt the end and never stand in doubt;
Nothing's so hard but search will find it out. — Richard II

God hath made man upright, but they have sought out many inventions. — Ecclesiastes

Science moves but slowly, slowly, creeping on from point to point. — Tennyson

. . . and out of olde bokes, in gode feith
cometh al this new science that men lere. . . — Chaucer

Experimental Loop
. . . at certain revolutions all the damn'd
Are brought, and feel by turns the bitter change
Of fierce extremes, extremes by change more fierce
From beds of raging fire to starve in ice
Their soft ethereal warmth and there to pine
Immovable, infix'd and frozen round
Periods of time; thence hurried back to fire. — Paradise Lost

Waste Disposal
. . . As thou these ashes, little Brook, will bear
Into the Avon, Avon to the tide
Of Severn, Severn to the narrow seas
Into main ocean they. . . . — Wordsworth

Publicity
. . . That paragon's description and wild fame
One that excels the quirks of blazoning pens. . . — Othello

. . . To Berkeley every virtue under heaven. . . — Pope

Lectures
. . . Fire in each eye and papers in each hand
They rave, recite and madden round the land. — Pope

. . . And when you stick on conversation's burrs
Don't strew your pathway with those dreadful "urrs." — Oliver Wendell Holmes

Authors
. . . And so I penned it down, until at last it came to be
For length and breadth the bigness which you see. — John Bunyan

. . . The mob of gentlemen who wrote with ease. . . — Pope

You write with ease, to show your breeding
But easy writing's curs't hard reading. — Sheridan

"N.E." Editorial
. . . S'death, I'll print it
And shame the fools. . . — Pope

"Tangent"
. . . While pensive poets painful vigils keep
Sleepless themselves, to give their readers sleep. — Pope

The "Unclear Times"
. . . Though it make the unskilful laugh
Cannot but make the judicious grieve. . . — Hamlet

You beat your pate and fancy wit will come
Knock as you please—there's nobody at home. — Pope

GRAPHITE:

Its Properties and Behaviour

By W. G. O'DRISCOLL, M.Sc.
(*Research Manager, Culcheth Laboratories, U.K.A.E.A., I.G.*)
and J. C. BELL, B.Sc., A.Inst.P.
(*R. and D. Branch, Windscale, U.K.A.E.A., I.G.*)

The physical, mechanical and nuclear properties of graphite were dealt with in the preceding issue. The effect of irradiation in a reactor on these properties is here discussed.

Part II. Effect of Reactor Conditions

NEUTRON irradiation of graphite brings about marked changes in properties due to damage to the crystal lattice. In the moderating process energy is transferred from the neutrons to the carbon atoms and, with energetic neutrons, atoms may be displaced from the lattice. Many of these displaced atoms will themselves possess a high kinetic energy and will displace further atoms as they are slowed down. For example, a neutron of 2 MeV energy will cause some 1,900 displacements as it is slowed down to thermal energies. The energy required to displace an atom from its lattice position is about 25 eV. Many of the atoms displaced return immediately to vacancies left in the lattice or are trapped at other defects or at crystallite edges. However, sufficient atoms remain in interstitial positions, either singly or as complexes, to affect the properties of the material, the magnitude of the effect being dependent on the neutron dose received, and on the temperature of irradiation.

Growth

Irradiation causes dimensional changes in graphite. The interstitial atoms tend to push the lattice planes of the crystal apart causing an increase in the inter-layer (c) spacing. At the same time, the presence of vacancies in the lattice planes causes a reduction of the inter-atomic (a) spacing in these planes. These changes in the crystal are much larger than the measured changes in the bulk polycrystalline material, presumably because the crystallites can expand into pores. That this is so has been demonstrated by work on graphites of the same composition but of different densities which showed that the denser materials grew more under irradiation[41]. The radiation-induced dimensional changes in some American graphites are shown in Fig. 18.

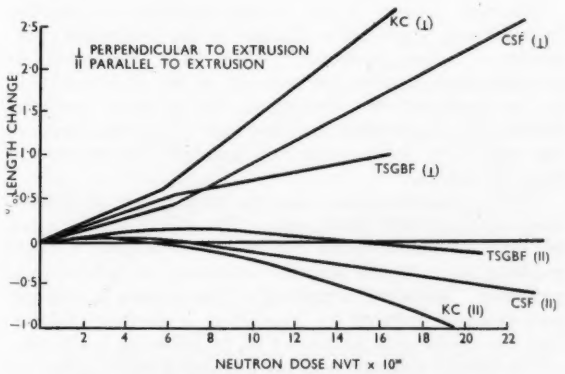


Fig. 18.—Irradiation growth of various graphites (42).

All artificial graphites show a certain degree of preferred orientation of the crystallites, the amount depending on the method of manufacture; under irradiation the growth will be greater in a direction perpendicular to the preferred direction of orientation of the crystal planes. The magnitude of the growth will also depend on the size of the crystallites in the graphite and wide variations in growth are observed between graphites prepared from different cokes and by different processes.

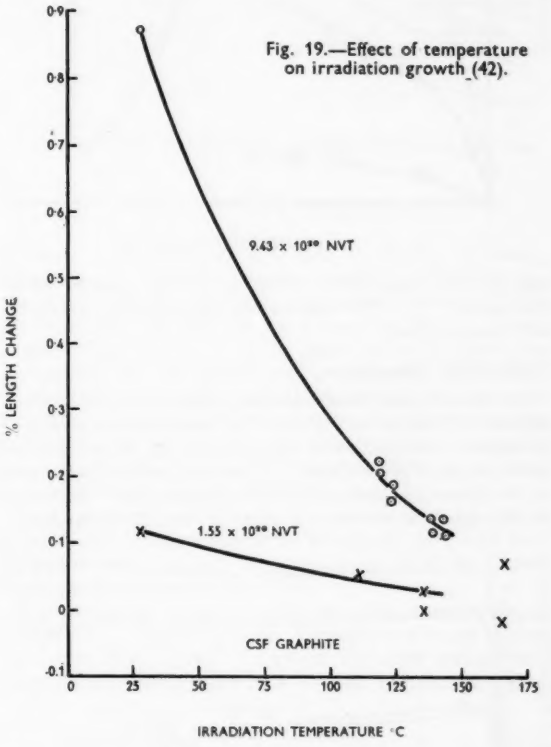
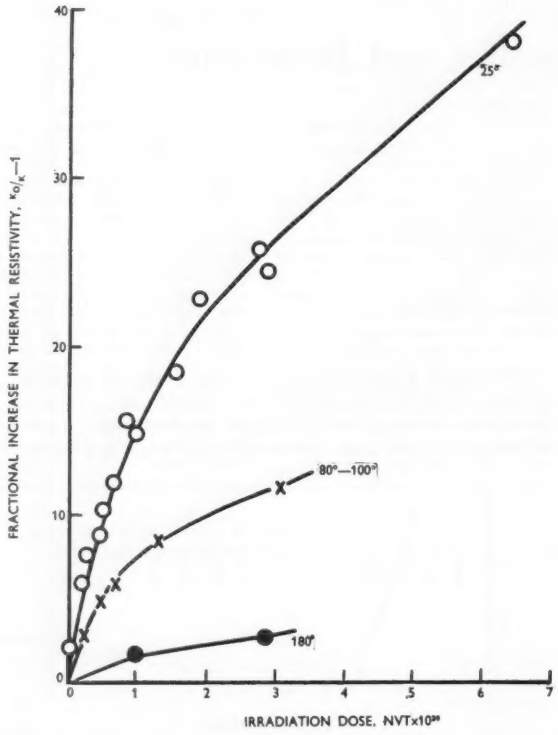


Fig. 19.—Effect of temperature on irradiation growth (42).

The measurements[42] shown in Fig. 18 were made on material irradiated at 30°C. Fig. 19 shows the effect of the temperature of irradiation on the growth in the direction perpendicular to extrusion, i.e., perpendicular to the preferred direction of orientation.

An interesting correlation is observed between the growth rates of various graphites and the coefficients of thermal expansion of the unirradiated materials. There is a linear relationship between these two properties, a material of

Fig. 20.—Increase in thermal resistivity as a function of irradiation dose and temperature (°C) (43).



high thermal expansion exhibiting greater growth under irradiation[42, 43]. This relationship only holds for relatively low neutron doses.

Conductivity Changes

The thermal and electrical conductances are particularly affected by irradiation. The crystal imperfections produced by neutron bombardment cause scattering of the thermal waves in graphite and lead to large increases in its thermal resistivity at low temperatures of irradiation[43]. Increases of thermal resistivity greater than 50 have been reported[41].

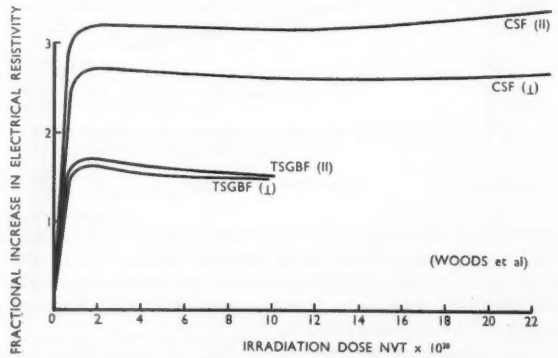
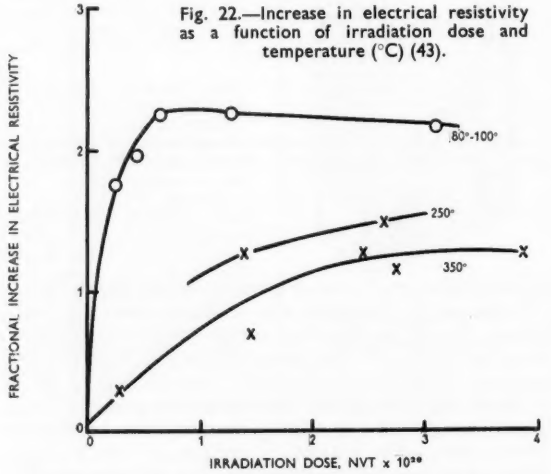


Fig. 21.—Effect of irradiation on electrical resistivity of various graphites (42).

This change is also sensitive to irradiation temperature[43] (Fig. 20) and at temperatures above about 400°C seems to saturate at a constant low value[44].

The conduction of electricity through the graphite is also affected because of the new scattering centres present. The electrical resistivity rises sharply to a peak value during the early part of the irradiation and then shows some recovery before again increasing slowly at higher doses[42] (Fig. 21). At higher irradiation temperatures the effect is very much reduced[43] (Fig. 22).

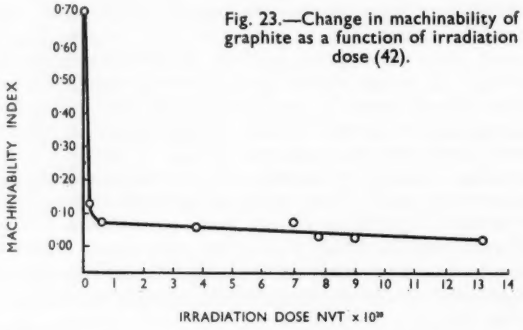
Fig. 22.—Increase in electrical resistivity as a function of irradiation dose and temperature (°C) (43).



The difference between the behaviour of electrical and thermal resistivity may be explained by the fact that the increase in electrical resistivity due to scattering by lattice defects is offset by a simultaneous increase in the number of current carriers as evidenced by the effect of irradiation on the Hall[45] coefficient.

Changes in the coefficient of thermal expansion are not significant below a dose of 2×10^{20} neutrons/cm², though for doses above this, the coefficient increases slightly[43].

Fig. 23.—Change in machinability of graphite as a function of irradiation dose (42).



Neutron damage to the crystal structure of graphite brings about appreciable changes in the mechanical properties. Those properties which are developed in graphitization, due to the ordering of the structure, tend to be destroyed by irradiation, thus graphite becomes harder, less machinable and stronger. The magnitude of the effect on some American graphites is shown[42] in Figs. 23 and 24.

As for the other properties, the temperature of irradiation is of particular significance. This effect[43] will be noted in Fig. 25 which shows the variation in the Young's modulus of a British graphite irradiated at various temperatures. Davidson[5] suggests that the increase in strength and modulus induced by irradiation is further evidence that the mechanical properties of graphite are a function of the crystal structure and not associated with contact of the binder.

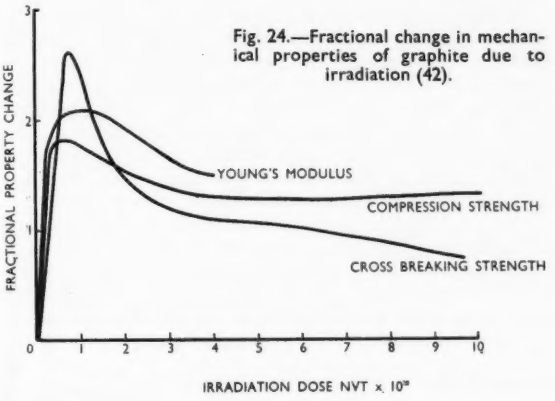


Fig. 24.—Fractional change in mechanical properties of graphite due to irradiation (42).

Energy Storage

Perhaps the most striking of the effects of neutron bombardment on graphite is the phenomenon known as stored energy. This is the strain energy associated with the distortion produced in the crystal. The energy can appear as heat when the irradiated graphite is heated above its irradiation temperature. The amount of this energy can be measured as the difference between the heats of combustion of irradiated and unirradiated material. Fig. 26 shows how the total[42] stored energy builds up under irradiation.

Of more practical value in interpreting the phenomena, however, is the annealing spectrum of the stored energy. Examples of annealing spectra obtained by raising the temperature of the material at a constant rate of 10°C/min and measuring the heat out are shown[42] in Fig. 27. It will be noted that parts of some of these curves lie above the true specific heat of graphite and, consequently, if the temperature of the graphite is raised rapidly into this temperature range, it will become self-heating. This effect is shown in Fig. 28. The samples have been immersed in a constant temperature enclosure and their time-temperature relationships determined. Very rapid self-heating can occur.

As the dose increases, the peak in the annealing spectrum at about 200°C passes through a maximum value and then decreases, more damage being accumulated at the higher annealing temperatures (Fig. 27).

The storage of energy is sensitive to the temperature of irradiation. For irradiation temperatures much above 100°C the 200°C peak disappears, although energy continues to be stored which can only be released at higher

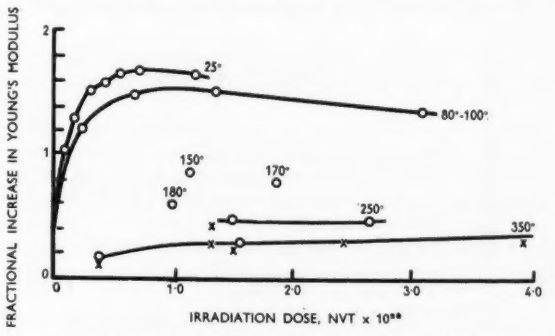
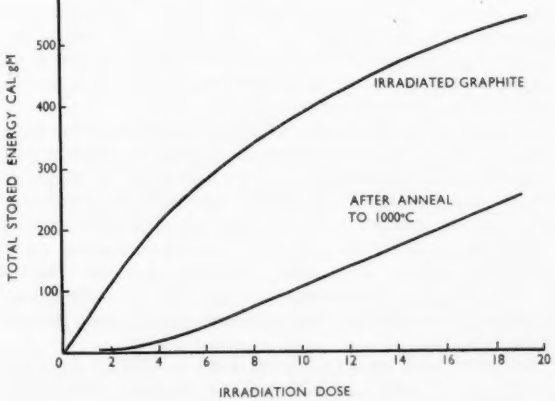


Fig. 25.—Changes in Young's Modulus as a function of irradiation dose and temperature (43).
O by method of flexural vibrations.
X in compression.

Fig. 26.—Build-up of total stored energy as a function of irradiation dose (42).



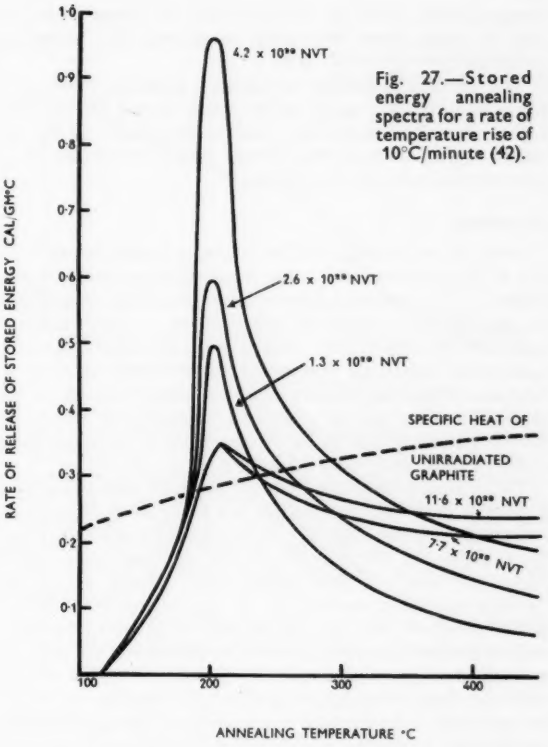

RATE OF RELEASE OF STORED ENERGY CAL/GM°C
4.2 x 10²⁰ NVT
2.6 x 10²⁰ NVT
1.3 x 10²⁰ NVT
SPECIFIC HEAT OF UNIRRADIATED GRAPHITE
11·6 x 10¹⁹ NVT
7·7 x 10¹⁹ NVT
ANNEALING TEMPERATURE °C

Fig. 27.—Stored energy annealing spectra for a rate of temperature rise of 10°C/minute (42).

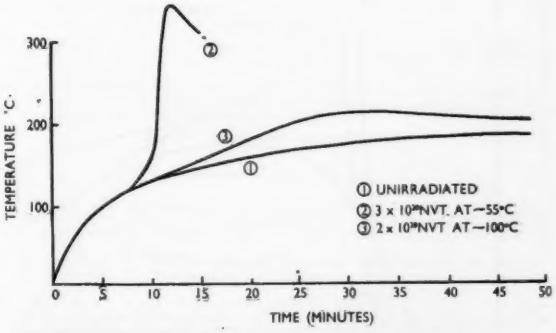


Fig. 28.—Self-heating of irradiated graphite when samples are immersed in a constant temperature enclosure.

temperatures. This is evident from the lower curve in Fig. 26 which shows the energy remaining after annealing to 1,000°C.

The amount of energy stored in a graphite varies with the crystallite size, more energy being stored in the more highly crystalline materials. This is illustrated[42] in Fig. 29 where a graphite and two carbons (which are made up of microcrystallites) are compared.

Annealing

Some of the damage to the crystal structure is annealed out at temperatures above the irradiation temperature and studies of the annealing spectra have been made in attempts to identify the nature of the defects. Four different methods[42] have been used. These are, isothermal annealing, asymptotic annealing (annealing for extended periods of time at a fixed temperature until no further change in the property studied can be detected), tempering (in which the property is measured as the temperature is raised at some uniform rate) and pulse annealing.

These studies indicate that the damage remaining at a particular time during annealing is a function of the amount of damage present originally, the annealing temperature and the duration of the annealing. For neutron doses below about 10^{20} n.v.t. at low temperature, almost all of the damage can be annealed out at temperatures[42] of about 400°C (Figs. 30, 31). As the neutron dose increases, however, and more complex defects are produced, the proportion of damage which can be annealed out at 400°C decreases and a substantial part of the damage can only be annealed at temperatures approaching the graphitizing temperature. The recovery of a particular property on annealing depends, of course, on how that property is dependent on the type of defect being annealed. We may take as an example, total stored energy, which, for material irradiated to a high dose shows two main regions of annealing, one in the region of 200°C and one between 1,000°C and 1,500°C. This is illustrated[42] in Fig. 32. These two regions are joined by a third in which annealing takes place at a fairly constant and lower rate.

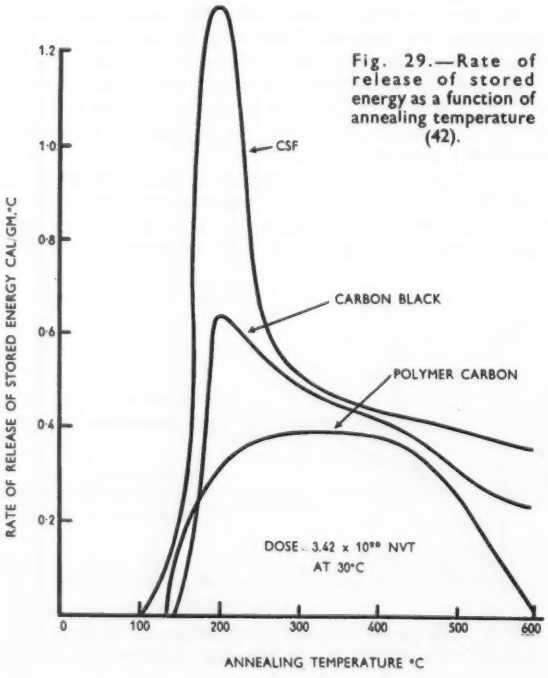


Fig. 29.—Rate of release of stored energy as a function of annealing temperature (42).

At high temperatures of irradiation (say, above 250°C) an important phenomenon known as radiation annealing occurs. Annealing at a particular temperature in the presence of a neutron flux is more effective than thermal annealing alone at that temperature. This may be explained as the break-up of damage complexes by neutron hits, thus producing more mobile single defects, or by the concept of thermal spikes, in which intense local heating of the lattice is caused by high energy collisions of carbon atoms.

The considerable complexity of the annealing spectrum of highly irradiated graphite has made the formulation of anything more than a qualitative model extremely difficult. For low irradiation, considerable progress has, however, been made in the understanding of the damage and annealing of electrical properties and stored energy.

Compatibility

Two direct effects due to irradiation on the compatibility of graphite with CO_2 are possible, namely, irradiation damage of the graphite itself and activation of the CO_2 by radiation. Though there is evidence that irradiated graphite is more susceptible to thermal oxidation than unirradiated material, effects of CO_2 irradiation are more significant.

The radiation-induced reaction was first studied by Harwell workers in CO_2 loops in BEPO, further information has been obtained from the operation of Calder and from slow bleed rigs in DIDO[34]. Estimates of the rate of reaction have been made both by direct weight loss measurements of graphite samples and indirectly, by determination of the rate of CO production.

The initial studies in a glass loop in BEPO, in which

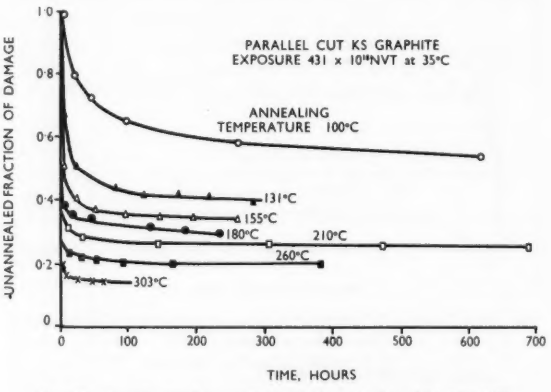


Fig. 30.—Isothermal annealing of electrical resistivity (42).

reaction was followed by CO analysis, indicated that the reaction was dependent on radiation intensity, pressure, and the ratio of gas to graphite under irradiation, but approximately independent of temperature in the range 25-350°C. The results could be interpreted in terms of reaction through a chemically reactive intermediary species produced by the irradiation of CO_2.

In its simplest form, the radiation-induced reaction consists of two steps, absorption of energy to produce an oxidizing species followed by its reaction with the graphite. The process, however, is probably a complex one, involving, for example, oxidation or ionization of the CO_2 and its breakdown to oxidizing species such as oxygen ions, atomic oxygen or ozone. It is clear, however, that the kinetics of the radiation induced reaction are entirely different to the thermal oxidation process where active sites appear to be involved.

Results[34] from an engineering loop in BEPO, designed to simulate Calder conditions in all respects other than

radiation intensity, enabled an estimate to be made of the mean net weight loss of graphite from the core of a Calder reactor. On the assumption that reaction was directly proportional to radiation intensity, the expected mean net weight loss from Calder would be of the order of 0.1%/yr. Observations in Calder[34], both by CO analysis and weight loss measurements of graphite monitoring specimens placed in the reactors, indicate a mean annual weight loss of 0.08%. Furthermore, the rate of production of CO was also shown to be proportional to the radiation intensity and pressure of CO_2. The rate of attack of graphite observed[34] in CO_2 at 10 atmospheres pressure and 500°C, in a high flux facility in DIDO was consistent in order of magnitude with the previous results.

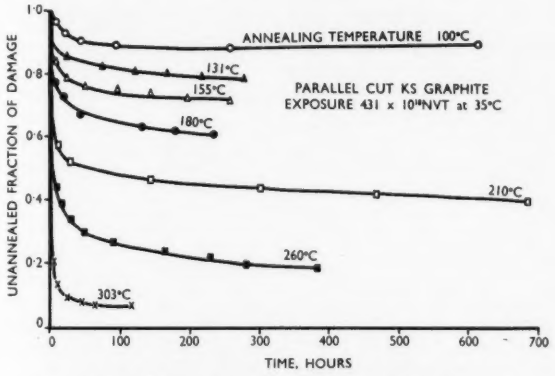


Fig. 31.—Isothermal annealing of Young's Modulus (42).

Though the reaction is as yet by no means fully understood, the evidence available may be interpreted as follows:—

(i) The reaction appears to be proportional to radiation intensity and to the total mass of gas irradiated. Thus for any specific geometric configuration, increased pressure brings about a proportional increase in reaction rate.

(ii) The reaction does not appear to have a marked temperature dependence, at least up to temperatures of about 500°C.

It is not possible to give absolute rates of reaction since the values relate the specific conditions of the experiment and the effects of all the individual parameters are not yet known. The results obtained from the various irradiation experiments are, however, consistent within an order of magnitude. For conditions appropriate to Calder, the rate of reaction would not be expected to give rise to any significant problems in reactor operation.

The compatibility of graphite with CO_2 may, however, be a limiting factor in the development of reactors operating at very high flux levels and pressures, unless the reaction is inhibited. The solution to this problem may lie in one of a number of methods of protection. Protection methods include the application of an inert protective to isolate the coolant from the graphite or the addition of an inhibitor to the gas phase which would preferentially react with the active species and reduce their concentration. In either instance, the absorption cross-section of the protective is important and must be of an acceptably low value. Preliminary work on protectives for graphite against thermal oxidation has been reported by McIntosh[33] *et al.* Subsequently, it has been shown[34] that coatings giving a measure of protection to thermal oxidation do not necessarily afford similar protection to the radiation-induced reaction.

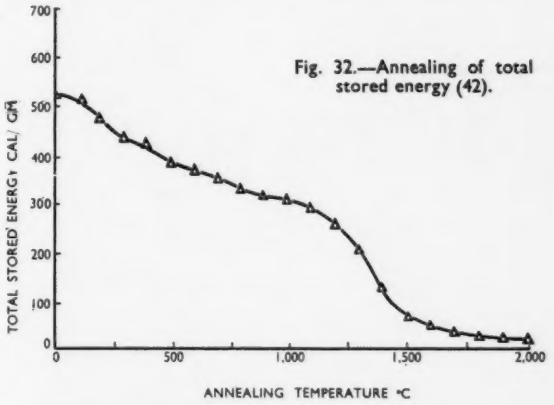


Fig. 32.—Annealing of total stored energy (42).

Little information is available on the effect of irradiation on the deposition of carbon from CO. There is no evidence of carbon deposition under Calder conditions. In experimental rigs it has only been directly observed at high CO concentrations. Both in the BEPO loop and in Calder the magnitude of leak rate of the system was such that it was the major factor controlling the equilibrium CO concentration.

The rate of oxidation of graphite in air is also affected by irradiation. Kosiba and Dienes[46] report increased rates for the graphite/oxygen reaction due both to irradiation damage to the graphite structure and to activation of the oxygen by gamma flux. The exposure of graphite, at 25-50°C, to a neutron dose of 4×10^{20} n.v.t. (producing about 2% displaced atoms) increases the thermal oxidation rate in the temperature range 250-450°C, by a factor of about 6. In the presence of 2×10^5 r/h gamma flux, the oxidation rate at 300°C was raised by a further factor of about 3.

Irradiation increases the rate of reaction between hydrogen and graphite. In experiments[30] in BEPO (thermal neutron flux of the order of 10^{12} neutrons cm²/sec), the rate of reaction at 500°C and 800 mm Hg total pressure, was increased by a factor of about 10 and at 600°C by about 4.5. The radiation induced reaction was dependent on the pressure in the system, increasing with increased pressure. The results could be accounted for qualitatively, by assuming that reaction proceeded through very short-lived active intermediaries, formed by the action of pile radiation on the hydrogen.

ACKNOWLEDGMENTS

The authors wish to thank Sir Leonard Owen (Managing Director) and Dr. H. Kronberger (Director of Research and Development), U.K.A.E.A., I.G., for permission to publish this article and to many colleagues for advice and permission to use previously unpublished results.

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THE ORNL CONFERENCE ON GAS-COOLED REACTORS

An information meeting on the U.S. gas-cooled power reactor programme was held at the Oak Ridge National Laboratory* on October 21 and 22. This was one of a series of such information meetings that the Atomic Energy Commission has sponsored covering various reactor projects. The following is a summary of the proceedings.

(Figures in brackets refer to the papers presented)

THE meeting began with a talk by Mr. U. M. Staebler, chief of the Civilian Power branch, AEC Division of Reactor Development, reviewing the United States' position on gas-cooled reactors, citing the X-10 and Brookhaven reactors, together with design studies such as the Daniels Pile, as indications of early U.S. activity. The interest aroused by U.K. successes during the past two years has led to a reappraisal of gas-cooled reactors in the United States.

Studies by the Oak Ridge National Laboratory†, by Kaiser Engineers with ACF Industries, and by the General Electric Co. have shown that in the U.S. enriched uranium is likely to be more advantageous in graphite-moderated gas-cooled reactors than natural uranium. This result arises mainly from the comparatively high capital cost of reactors of the improved Calder Hall type in the U.S. coupled with the relatively low cost of enriched uranium. It is thus worth while to use enriched uranium to increase fuel loading, increase operating temperature, and extend fuel burnup to perhaps 10,000 MWD/ton. Of all the new U.S. gas-cooled reactor designs described, only the gas-cooled heavy water moderated reactor being designed by General Nuclear Engineering Co. envisages the use of natural uranium.

The predominant activity in the U.S. gas-cooled reactor programme at the present time is centred on the design and construction of a helium - cooled graphite - moderated prototype power reactor. Design of this reactor is being carried out by the Kaiser Engineering Company with ACF Industries (2). Development work is being done at the Oak Ridge National Laboratory (3c, d) and at Hanford (4). Other U.S. activity includes the design of a heavy water-moderated gas-cooled reactor by the General Nuclear Engineering Company (7), a high-temperature pebble bed reactor by Sanderson and Porter Company (6), and a maritime reactor being designed for the Maritime Commission by General Atomic Company (9).

Fuel Elements

The fuel elements chosen for nearly all of the designs presently under consideration in the U.S. are clusters of UO_2 rods ranging in size from $\frac{1}{4}$ in. to $\frac{3}{4}$ in. in diameter, and in number from 7 to 19 or more. The ORNL and ACF designs have 7 hollow rods, approximately $\frac{1}{4}$ in. o.d. by $\frac{1}{16}$ in. i.d. The D_2O reactor of GNEC is to have 19 rods, 0.54 in. o.d. by 0.2 in. i.d., and the maritime reactor being designed by General Atomic Company will have 19 solid rods, 0.25 in. in diameter.

The sheath material chosen in nearly every case has been stainless steel ranging from 0.01 to 0.02 in. thick, and with a maximum surface temperature of 800°C including hot spots. Aluminium and magnesium lack the necessary high-temperature strength. Zirconium and its alloys are too susceptible to attack by gaseous impurities in helium, such as CO_2, H_2O, O_2, and H_2. Beryllium is not yet sufficiently developed, and it was believed would limit the fuel surface temperature to about 600°-650°C. For the D_2O reactor, GNEC hopes eventually to use beryllium with natural uranium oxide, but plans steel-jacketed enriched uranium oxide for the prototype reactor.

A number of possible difficulties with fuel elements of this sort have been recognized. The extent of fission gas evolution and its effect on the fuel capsule is not well known. It is believed that the rate of gas evolution may depend on the presence or absence of a gas annulus between the UO_2 and the jacket. Experiments have been performed at ORNL (3c) on the effects of creep buckling on the inward collapse of stainless steel capsules against the contained UO_2 when under external pressure. Wrinkles were formed in 0.75-in. diameter capsules and a 0.020-in. thick wall with diametral clearances of as little as 0.005 in. between the capsule and the contained slug. There is some concern that cracks will form at the wrinkles as a consequence of pressure and temperature cycling, and further tests are to be run to investigate this.

The effects of channelling of coolant flow and the resulting non-uniform temperature distributions around the surface of the capsules in a cluster are also not yet well known, but may prove to be quite serious. Experiments are under way at ORNL and are planned at ACF to investigate the extent of the difficulties that may arise from this cause.

Coolant Gases

The relative heat transfer performance, pumping power requirements, and other characteristics of gases that might

* Operated for the U.S.A.E.C. by Union Carbide.

† The ORNL GCR-2 study was discussed at some length in *Nuclear Engineering*, July, 1958.

be used as reactor coolants were discussed in several papers. In all of the recent power reactor studies the choice of coolant has narrowed quickly to CO_2 and helium. Other gases such as nitrogen, CO, air, and especially argon involve too great expenditure of pumping power. Hydrogen is still thought to be hazardous, in addition to its poorly-known effects on the strength of metals. It has generally been concluded that, while helium is usually better than CO_2 from a thermodynamic viewpoint, the controlling factors are chemical reactivity and availability. The compatibility of graphite and CO_2 at temperatures much above 500°C is still sufficiently doubtful that the graphite designs all employ helium. The D_2O reactor with insulated Zircaloy tubes will employ CO_2 (7).

The availability of helium was discussed (3b) and shown to be adequate to support a large number of reactors for many years.

Virtually all of the free world's known reserves of helium are in natural gas from fields within a few hundred miles of the Texas panhandle. In all cases the gas-bearing strata overlie granite which has released helium from the radioactive decay of uranium. Only a part of the gas being consumed from these fields is currently processed so that only about 10% of the readily-recoverable helium is obtained. Plans are under consideration in Congress to recover a large part of that obtainable and store it in a spent gas field. If this is done promptly, reactors capable of producing 15,000,000 kW of electricity could be operated for 50 years on about 1% of the available helium. This estimate is based on the assumption that the leakage rate could be reduced to about 0.1%/day.

Current Designs

Much of the emphasis in the Commission's programme is being placed on the design and construction of a 30-MWE prototype of the helium-cooled power reactor (2). This reactor will operate at a helium pressure of 315 p.s.i.a., with an inlet temperature of 515°F, and an outlet temperature of 1,050°F. Installed in a cylindrical pressure vessel, the graphite core will have an effective diameter of 11 ft and a height of 14.5 ft; it will have a 2-ft thick reflector on the sides and 2.5-ft thick reflector at each end. Fuel elements will consist of clusters of seven ¾-in. diameter UO_2 rods jacketed with stainless steel and supported by graphite sleeves. The lattice pitch of 8.1 in. yields a somewhat under-moderated lattice, reflecting the use of fuel enrichment to increase the fuel loading of the reactor. A feed enrichment of about 2% is expected to produce a fuel burnup of 10,000 MWD/ton.

An extensive fuel element development programme is under way at the Oak Ridge National Laboratory. The programme includes extended in-pile irradiation of full-scale fuel element capsules and accelerated tests of miniaturized capsules to determine the integrity of the capsules and the extent of fission gas released. These tests will be performed at capsule surface temperatures of 1,000 to 1,500°F, well above the temperature level maintained in previous programmes directed at water-cooled reactors.

A description was given (7) of the CO_2-cooled heavy-water-moderated reactor being designed by the General Nuclear Engineering Company for the East Central-Florida West Coast group of utilities. GNEC hopes to achieve both low capital costs and low fuel costs with natural uranium. The long-range objective of the programme is a 200 MWE reactor with a core 18 ft high by 24 ft in diameter. Fuel elements would be jacketed in beryllium with a maximum surface temperature of 1,200°F. yielding an outlet gas temperature of 1.050°F. Immediate plans are for a prototype reactor 12 ft high by 10 ft in diameter, to have stainless-steel-jacketed fuel elements. The prototype will require 1.84% enriched uranium. In both designs the coolant and the moderator are separated by ⅛-in.-thick pressure tubes 5.0 in. in diameter. Scalloped alumina liners are being investigated to insulate the pressure tubes from the hot gas. The moderator is to operate at a temperature of 217°F and a pressure of 15 p.s.i.

There is considerable interest in the United States in fuel-impregnated graphite fuel elements (6, 9, 11c). An interesting example of this approach is the pebble-bed reactor, which has been under study for several years by the Sanderson and Porter Company. A design was described (6) in which the core structure consists of a cluster of six large hollow graphite cylinders with an overall core diameter of about 9 ft, forming seven chambers roughly 3 ft in diameter. The fuel elements consisting of 1.5-in.-dia impregnated graphite balls, are fed into the chambers in the graphite cylinders. Helium at 1,000 p.s.i. enters the reactor at 525°F and leaves at 1,200° to 1,400°F. Steam is produced at 1,000°F and 1,450 p.s.i. pressure. The principal advantages claimed for this system are ease in loading and unloading fuel and simplification of the head end treatment in fuel reprocessing, as well as high thermodynamic efficiency. Several methods of manufacturing the fuel elements have been investigated and an in-pile test programme is under way at the Battelle Memorial Institute.

Applications of gas-cooled reactors to ship propulsion were discussed (9, 11b). In both instances a relatively small graphite-moderated reactor was selected. The reactor coolant is used as the working fluid in the thermodynamic cycle, in one case (9) with a gas turbine and in the other (11b) with a reciprocating engine directly coupled to the reactor. Advantages claimed for this latter novel

PAPERS READ AT THE MEETING

1. **The A.E.C. Gas-Cooled Power Reactor Programme** (U. M. Staebler, A.E.C.).

2. **Gas-Cooled Power Reactors** (Kaiser Engineers—ACF Industries, Inc.). **Introduction** (J. S. Ritchie); **Techniques for Optimizing Power Plants** (L. L. Kintner); **Reactor Physics** (P. M. Wood); **Introduction to Kaiser-ACF Nuclear Power Plant** (R. S. Miller); **Reactor Core Structure** (F. R. Rulien); **Reactor Hazards** (P. I. Perry); **Vessel and Charge-Discharge Machine** (H. D. Young); **Control Rods and Service Machine** (G. W. Fieser); **Steam Generators, Blowers, Seals, etc.** (J. P. Ernst).

3. **Gas-Cooled Power Reactors** (Oak Ridge National Laboratory).
(a) **Introduction** (W. H. Jordan).
(b) **Design of Helium-Cooled Power Reactor—GCR-II** (A. P. Fraas).
(c) **Choice of Materials and Materials Development** (W. D. Manly).
(d) **Materials Compatibility and Fuel Element Test Programme** (D. B. Trauger).

4. **Graphite Studies of the Gas-Cooled Reactor Programme** (D. E. Baker, G.E.C., Hanford).

5. **Construction of the Bradwell Reactor (colour film)** (Sir Claude Gibb).

6. **The Pebble-Bed Reactor** (S. T. Robinson, Sanderson and Porter).

7. **Design Concept for Gas-Cooled Pressure Tube D_2O Moderated Reactor** (G. M. Roy, General Nuclear Engineering Co.).

8. **Parametric Studies of the Gas-Cooled Reactor Concept** (H. W. Heacock, G.E.C., Hanford).

9. **Maritime Gas-Cooled Reactor** (T. H. Pigford, General Atomic).

10. **High-Temperature Processing Experiments** (J. P. McGee, Bureau of Mines).

11. **Advanced Systems Studies** (Oak Ridge National Laboratory).
(a) **Cost as a Design Criterion** (M. Bender).
(b) **Advanced Design Studies** (A. M. Perry).
(c) **Hazards Evaluation** (W. B. Cottrell).
(d) **Advanced Materials Development** (J. H. Coobs).

plant were an overall thermal efficiency of about 30% with a peak gas temperature of only 1,100°F (as compared to the 1,300° to 1,400°F temperature required for a gas turbine) and the elimination of heat exchangers for regeneration.

Safety Considerations

Hazards criteria for gas-cooled reactors were discussed (11c) as measures of the need for containment. The power density, the amount of radio-activity in the cooling gas, and the reactor operating temperatures were considered as the most important parameters. The reactor core power density largely determines the temperature over-shoot in transients or in the event of coolant flow interruption. The design operating temperature determines the margin available for temperature over-shoots with given fuel element materials as well as the likelihood of a graphite fire in the event of a gross rupture in the gas system. The activity normally in the reactor cooling gas largely determines the dose to people downwind of the reactor in the event of a large gas leak. The fission gas leakage from UO_2 encased in graphite capsules was then discussed and the results of analyses presented. These indicated the possibility that, by slowing down gas leakage through the graphite so that only the longer-lived isotopes would enter the gas stream, and by providing a by-pass clean-up system with a charcoal trap, there is a possibility that the level of the activity in the coolant might be kept to 1,000 to 10,000 curies. This should not be too high for carefully scheduled maintenance, and might not require extra containment provisions.

A refreshing and stimulating change from the abstractions and design studies of the previous speakers was provided in a sprightly talk on construction of the Bradwell plant by Sir Claude Gibb, who pointed out how the British designers had made the best of natural uranium and CO_2, the only materials they had available. Later, in a colourful after-dinner speech, Sir Claude discussed the geopolitical aspects of nuclear power, emphasizing the part that it must play in the U.K.

Nuclear Coal Gasification

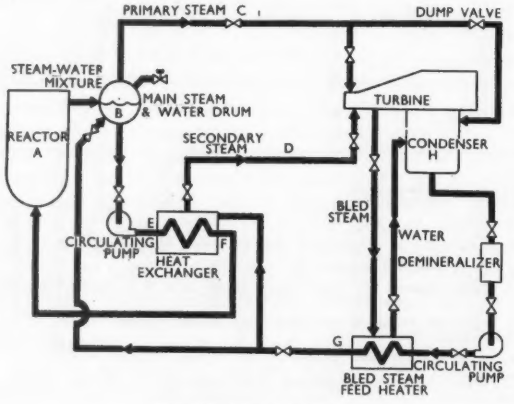
A programme on the gasification of coal with nuclear power is being carried out by the AEC and the Bureau of Mines (10). Although petroleum constitutes only 10% of the known fossil fuel reserves, it is currently being used to supply 60% of the energy consumed. Since much of this is for automotive and similar applications where coal is not suitable, there is a long-range need for a good coal gasification process in which nuclear power would supply the energy for the water gas reaction. Cheap hydrogen from this process would be valuable in the reduction of iron ore, for example. With nuclear power the water gas reaction can be carried out satisfactorily at 30 atm in the temperature range from 2,000° to 2,500°F.

The process proposed would employ a graphite-uranium fuel element which would serve to give 2,000°F helium. The helium would be recirculated through a heat exchanger to supply heat to the process. A pilot plant for the process has been built and testing has been carried out with electrically-heated helium circulated at temperatures up to 1,800°F. Preliminary estimates indicate that it will be economical at nuclear fuel costs of $0.80 to $1.00 per million B.t.u.

THE SENN SCHEME

Preliminary Details

AS is generally known, the contract for the construction of the SENN project in Southern Italy is being placed with the International General Electric Co. of New York. No official release of technical information has yet been made but a certain amount of material has appeared in the official publication of the I.R.I. (Instituto per la Riconstruzione Industriale).



Simplified flow diagram.

From the flow diagram reproduced herewith it can be seen that the proposed reactor is of the double-cycle boiling water type, feeding a 106 MW (200 MVA) turbo-alternator with 700,000 kg/h (1,540,000 lb/h) of high pressure steam and 217,000 kg/h (478,500 lb/h) of low pressure steam, the pressures and temperatures at various points in the circuit being given in Table 1 (British equivalents are approximate). The reactor heat output is 508 MW, and the figure given for plant efficiency is 29.6%.

The fuel is uranium oxide (2% enrichment) canned in zirconium, the uranium equivalent of the total charge being 45.4 tonnes. Burn up figures given are equivalent to 13,000 MWd/t, the estimated life of one charge being approximately four years.

The diameter of the steel sphere acting as an outer containment for the plant is 52 m or just over 170 ft, designed for a working pressure of 1.5 kg/cm² (21 p.s.i.).

TABLE 1

Operational Pressures and Temperatures at Various Points on Flow Diagram

Point		Pressure		Temperature	
		kg/cm²	p.s.i.	°C	°F
A	Reactor	71.5	1,015	286	545
B	Main drum	69.6	990		
C	Primary steam	67.8	965	282	540
D	Secondary steam	33.4	475	238	461
E	Heat exchanger inlet			277	532
F	Heat exchanger outlet			267	512
	Feed heater inlet	89	1,265	31.1	87
G	Feed heater outlet			191	376
H	Condenser	0.043	27.7 in vacuum	39.5	104

The "Mary Kathleen"

Opening of Australia's First Privately-owned Uranium Mine

AUSTRALIA'S first uranium mine owned and operated by private industry was officially opened by the Prime Minister, Mr. R. G. Menzies, on October 27. The mine, named Mary Kathleen, after the wife of the prospector who discovered the deposits in July, 1954, is about 40 miles from Mt. Isa in Northern Queensland.

The project—which involved building a town to house a thousand people, a reservoir and a complete ore treatment plant—was completed in 26 months. Mary Kathleen is, in fact, a remarkable example of Anglo-Australian co-operation. As soon as the original finding had been confirmed, the syndicate of eight prospectors formed, with Australasian Oil Exploration, a joint company, Mary Kathleen Uranium. Subsequently the Rio Tinto group became interested in the venture through their Australian subsidiary.

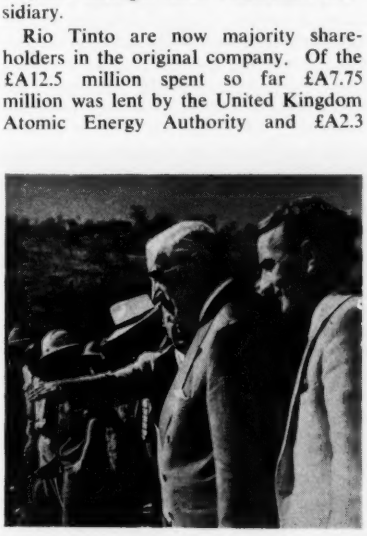
Rio Tinto are now majority shareholders in the original company. Of the £A12.5 million spent so far £A7.75 million was lent by the United Kingdom Atomic Energy Authority and £A2.3 million by Rio Tinto of Australia. In 1956 the U.K.A.E.A. contracted to purchase 4,500 tons of uranium concentrate from the mine at a cost of about £A40 million. Independent mining consultants have estimated the present ore reserves at 6.6 million short tons, averaging 0.143% uranium oxide. At an estimated recovery of 89% these reserves should yield 8,400 tons of uranium oxide over a 14-year period. The first 100 tons —produced since the extraction plant came into operation in June—has already been shipped to the U.K.

An open-cast method of mining is used, the ore being transported by tractor-drawn equipment to the ore treatment plant a short distance from the deposits. The ore itself is unique amongst large-scale uranium producers, allanite, a rare earth silicate mineral being the chief source.

The treatment plant is of conventional design.

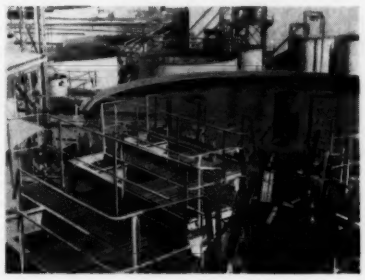
The crushing section has a capacity of 275 tons/hr from run of mine ore to a sized $\frac{3}{4}$ in. mill feed. The primary crusher is a 42 in. by 36 in. Jaques Traylor jaw unit set at 6 in. Secondary crushing from 6 in. to 2 in. is by a 5½-ft standard Symons crusher and final crushing to $\frac{3}{4}$ in. by a 5½-ft short head Symons crusher. Grinding is effected in a two-stage circuit utilizing one rod mill and two ball mills.

Finished pulp from the cyclone classifiers associated with fine grinding is dewatered from 32% to 60% solids before sulphuric acid is added. Solids-solution separation and washing is carried out in a 5-stage counter current decantation plant. Clarification is achieved in two 8 ft by 16 ft Eimco precoat filters. The clarified liquor is pumped to a Permutit ion exchange plant, the final stage of the extraction process being precipitation by the Porter elution technique. The final product is the familiar crude diuranate—yellow cake.

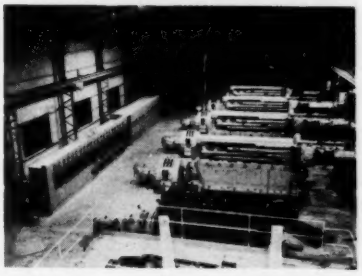


Mr. R. G. Menzies, the Australian Prime Minister, was shown work at the ore body by Mr. F. E. Hughes, chief geologist. (*Courier Mail* photograph.)

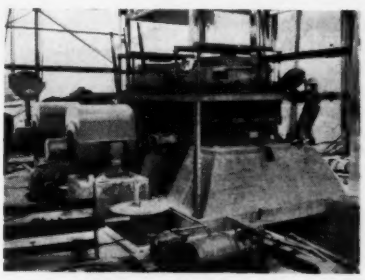
(Top of page) The mill with stove on left, power station centre background and the acid plant beyond it.



Leach tanks with thickener tank and tank farm at rear.



Power station with 4 Mirrlees-Brush 990 kW sets, 1 Ruston 525 kW unit and a waste steam 750 kW Brush turbo-alternator.



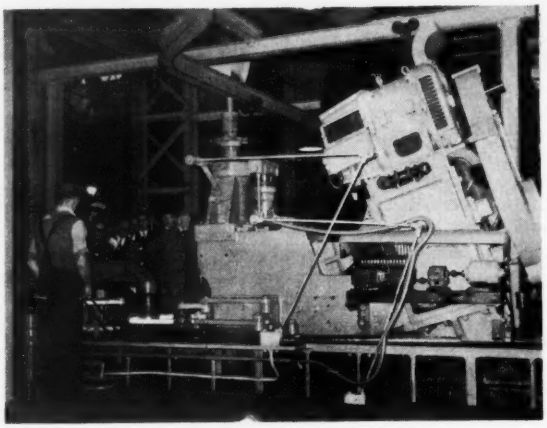
Symons cone crushers.

A ROLLING MILL FOR FORGED RINGS

Official Opening of Hingley's New Production Unit

DESPITE the advances made during the past decade or so in welding techniques, there are many situations where circular flanges or strengthening rings, made by bending from bar and welding, are not acceptable. The alternative method of cutting the ring from solid plate is also frequently ruled out, since it is impossible, by this means, to ensure uniformity of grain flow throughout the ring. Forging from the solid is, then, the only possible method and, with large rings, frequently presents considerable difficulties.

By courtesy of N. Hingley and Sons, (Netherton) Ltd., we were recently able to attend the official opening at their Netherton Works, of a new ring rolling mill for producing solid rings of large size, within small tolerances on a production basis. The mill was designed and built by the company's own staff.

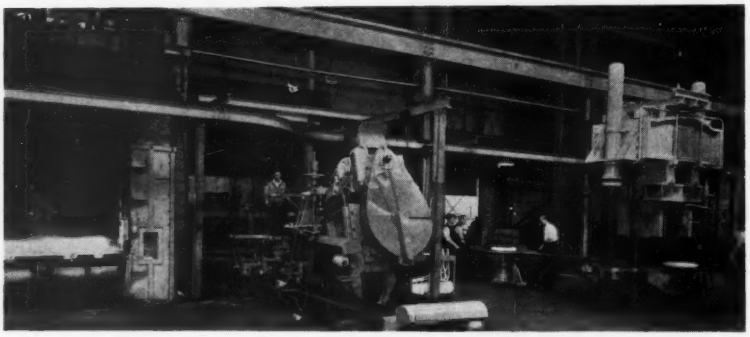


(Above) The first ring produced after the official start-up being removed from the "sizer" unit.

(Left) View of the rolling process in operation.

The "Mould"

The method of production of the "mould," as it is called before rolling, follows traditional methods, and is an object lesson in craftsmanship and teamwork. A square billet, preheated, is first roughly formed into an octagon under a steam hammer and is then up-ended and upset under the hammer into a "cheese" of roughly the correct diameter and thickness. After further rough rounding, it is then pierced by hammering a circular steel tool through the centre, and is then slung on a horizontal mandril and rotated under the hammer, being finished off with light blows until it is circular and concentric with the centre hole enlarged to the required diameter. It is then a finished "mould," and ready for the next operation. Steel moulds roughly estimated at about 1 cwt were being produced in a single heat. On the other hand it was observed that moulds of one of the Nimonic alloys required several heats, on account of the comparatively small temperature range over which they are capable of being worked.



A general view of the plant layout showing (from left to right) furnace, rolling mill, "sizer" unit and flattening press.

Rolling

In essence, the rolling mill consists of two vertical spindles carrying rollers, one of which is powered. The mould is placed over one roller and rotated by being brought into contact with the other, by reducing the distance between the roller centres sufficiently to grip the ring. A hydraulically powered carriage carries the moving roller, which applies a controlled squeeze to the ring. Horizontal rollers restrain expansion in the vertical direction so that the ring is rapidly and smoothly expanded to the required diameter and cross-section, the operation giving the correct grain flow around the ring. When the expansion has proceeded to within a short distance under the required diameter, the carriage is retracted and the ring—which may now be as large as 6 ft diameter—is removed by a quick-acting hoist and dropped over one of the auxiliary machines in the set-up. Generally known as the "sizer," this consists of an expanding segmental jig which stretches the ring to the required diameter. The ring, still hot, is passed down a roller conveyor to the last operation which consists of a squeeze between the platens of a hydraulic press, to flatten the ring in the horizontal plane. It is then ready for machining.

Types of Product

Rings are manufactured in a variety of non-ferrous metals, in carbon and stainless steel, and in heat-resisting materials such as the Nimonic series and in metals such as titanium. The average ring is produced truly circular, of uniform cross-section, and properly flat, to within $\frac{1}{16}$ in. of the finished machined dimension. Rings are produced up to approx. 500 lb.

The company also produces a wide range of rings made by flash butt welding, as well as the wide range of hot stampings, castings and forgings for which the Netherton Iron Works has a reputation extending back well over a century.

Computer Exhibition Preview

The Electronic Computer Exhibition at Olympia, London, is open from 10 a.m. to 8 p.m., daily, November 28 to December 4 (excluding Sunday). Price of admission is 2/6d. Admission to the Symposium, held within the Exhibition Hall, is by tickets obtainable from the Electronic Computer Exhibition, 11/13 Dowgate Hill, London, E.C.4.

ALTHOUGH the Electronic Computer Exhibition which opens at Olympia, London, on November 28, is concerned with all computer applications—commercial, industrial, research, and so on—it does provide remarkable evidence of the impact of this recently developed science on the development of nuclear energy. A large proportion of the forty or so exhibitors have already sold machines to the A.E.A. or to the rapidly expanding manufacturing side of the industry. Others are offering computational facilities on a cost-plus basis—a facility which in itself has already done much to reduce the time factor involved in many complex calculations.

Reactor operation—or, for that matter, reactor simulation—is a natural subject for the computer. It is noteworthy that following the lead established by the A.E.A. in ordering data processing equipment for both Capenhurst and Dounreay the new C.E.G.B. nuclear power stations will also have fully automatic equipment for recording temperatures and conditions of the fuel elements.

On the research side both digital and analogue computers are already extensively used either to speed calculation or to investigate some of the intransient phenomena associated with nuclear techniques. More recently analogue computer techniques have been successfully applied to the task of reactor simulation. A contract for a simulator to train operators at Berkeley and Bradwell has just been placed with Elliotts by the C.E.G.B.

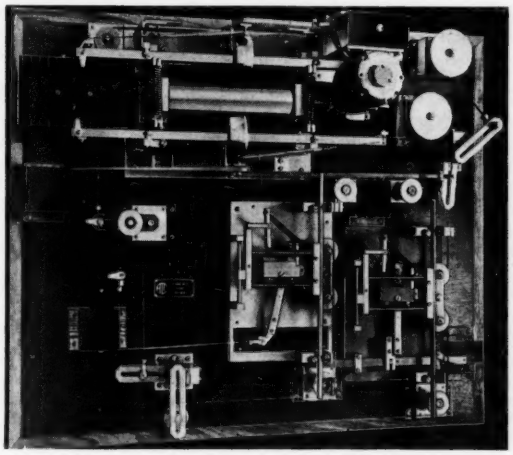
The notes which follow give a brief indication of the stands likely to prove most interesting to those readers of *Nuclear Engineering* who are able to visit the exhibition.

Air Trainers Link

This company, which has many years' experience of building simulators for the aircraft industry, has recently proposed a nuclear power station simulator based on a d.c. analogue equipment. The system employs logarithmic computations in the case of kinetic equations and the equipment therefore functions throughout the required range without the necessity for rescaling. For instructional purposes, Air Trainers offer tape corrected mechanical units capable of solving differential equations: one of these units can be seen in operation on the stand.

Benson-Lehner (G.B.)

Apparatus for reading information from punched cards or tape, or from cine film, showing it visibly in the form of a moving graph, as well as feeding it into data processing equipment. The decimal converter processes analogue inputs into digital outputs. The instrument can also produce the factors of the information visibly.



Mechanical analogue computer for instructional purposes. Assembled from components made by Air Trainers Link.

British Olivetti

A tape-to-card converter, operating at 600 digits a second. Using transistors and germanium diodes and including a magnetic core memory, the converter is claimed to be exceptionally flexible in data combination. Olivetti photo-electric reading equipment is also capable of 600 digits a second.

British Thomson-Houston

B.T.H. has pioneered the application of electronics to the control of machine tools and the co-ordinate position setting system is one of the most interesting examples. An automatic card-reader is used to control the settings, two sets of co-ordinates being fed in simultaneously. Samples of work produced by machines working under electronic control are shown.

Burroughs Adding Machine

The E101 computer is intended primarily for engineering and scientific applications. Magnetic drum storage capacity has been increased to 220 words. Data is entered manually through the keyboard of an accounting machine; programmed control obtained by a plug board with pin. Output is in the form of an accounting machine line printer or as punched paper tape.

With the Burroughs 205 and 220 computers magnetic drum and magnetic tape storage systems will handle up to 48 million words with input by paper tape or punched cards. The Burroughs system of converting the magnetic-stored information to punched cards, automatically, is also shown.

British Tabulating Machine

Major working exhibit is the 1201 Hec computer featured together with the 555 Hollerith plugged programme computer. The Hollerith stand covers all aspects of data processing and a complete range of input and output equipment can be seen. Information regarding the 1400 computer which is now in course of development is also obtainable.

The new Elliott 802 computer. The size has been kept small by the extensive use of printed circuits and transistors.

Leo digital computer in operation at the Corby office of Stewarts and Lloyds, where it is used for commercial accounting.

Creed

A new reader, faster than any developed before, is being introduced by Creed to present computer information in readable form. The new machine, the Model 3000 tape punch, reads at 3,000 words per minute.

Elliott-Automation Group

Elliott Bros. are collaborating with National Cash Register. They show a large National-Elliott 405 data processing system, complete with data-originating input and output equipment. The latest Elliott 402F floating-point scientific digital computer can be seen solving a variety of problems. A new general-purpose digital computer, the 802, demonstrates how the size of computing equipment has been reduced by the use of printed circuits, transistors and magnetic cores. The 802 combines the versatility of larger machines with a total size little greater than an office desk. The almost complete elimination of valves from the machine has made air-conditioning and cooling unnecessary.

The 802 also forms the heart of the Panellit 609 industrial data processing and information system. The 609 thus has the facility of high-speed scanning of up to 600 measurement points allied to computer control. The A.E.A. has already ordered an equipment based on the 609.

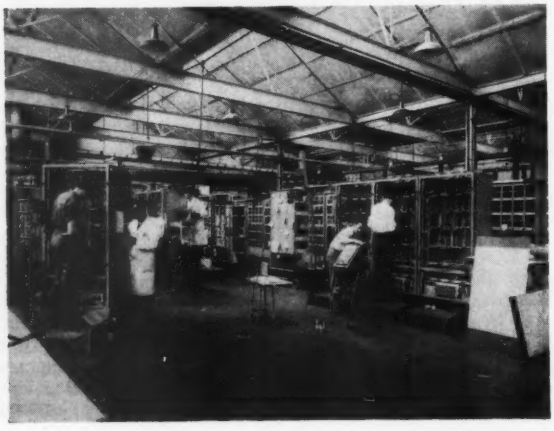
Another Elliott exhibit is a new high-speed tape reader, designed to handle standard 5, 7 and 8-hole punched paper tape at any speed up to 1,000 characters per second.

E.M.I. Electronics

EMIDEC 1100, a high-speed computer which employs the latest construction techniques, provides a comprehensive and flexible data processing system. Each section is individually plugged in to form a complete machine of great flexibility.

EMIDEC 2400, a new large high-speed data processing system, is said to be capable of scanning all the information contained in the Encyclopædia Britannica in less than four minutes. EMIDEC 2400 is being developed in conjunction with the National Research Development Corporation. As the computer is too large to show in entirety it is represented by its input multiplexing unit.

EMIAC 2, a general-purpose analogue computer, can be seen working on scientific problems.



EMIDEC 2400 under construction at the Hayes factory of E.M.I. Electronics. When completed this computer will have from 30 to 40 racks.

English Electric

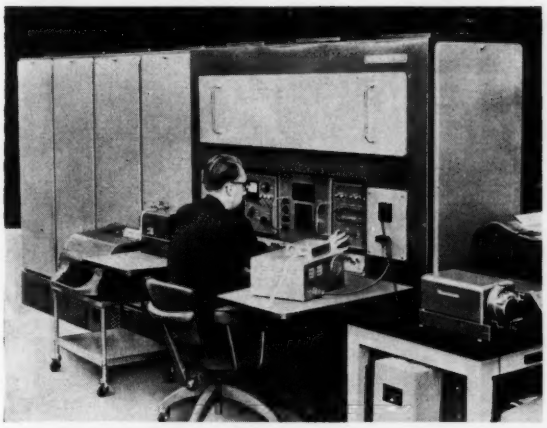
The well-known DEUCE digital computer is now available in two versions, the Mk. 1, intended mainly for scientific work, and the Mk. II, designed primarily to form the central unit of data processing systems. Their capabilities and characteristics are explained and discussed by experts who will be demonstrating them on the English Electric stand. There is a direct landline to the company's main computing centre at Stafford. The company stress the value of the extensive library of programmes and sub-routines which has been built up over the years since DEUCE was first developed. Also featured on the stand are a fully-operational LACE Mk. II analogue equipment and a new card-operated typewriter. The English Electric reactor simulator recently introduced for training operators is represented by a photographic display. A DEUCE Mk. 2 has been ordered by the A.E.A. for installation at Capenhurst where it will indicate optimum production schedules for the diffusion plant.

Fairey Aviation

The Fairey multi-purpose analogue computer, introduced early this year, is intended for investigations into the design of process plant, or for servomechanisms or for the solution of sets of non-linear differential equations such as those concerned with heat flow problems. There are two methods of problem patching, one of which consists of directly interconnecting the function units by plugging in short lengths of cable; alternatively there is a central patching system with removable, interchangeable patch boards.

Ferranti

A comprehensive range of equipment for business and administration, industry and scientific research is displayed on the Ferranti stand. The Perseus data-processing system, a large-scale commercial installation, is exhibited for the first time. Originally designed for commercial operation and costing about £300,000, it is the largest data-processing system yet made in Western Europe. The Pegasus



New type 950 digital computer by Metropolitan-Vickers Electrical.

Stantec Zebra digital computer (Standard Telephones and Cables).

computer (twenty-two are at present installed) is extensively used in universities and the aircraft industry. The Mercury computer, the largest and fastest electronic digital computer made in Europe, has already been ordered by seven nuclear authorities for research work in physics and engineering. An outstanding feature of Mercury is the new memory comprising small magnetic rings in an area of about $\frac{1}{4}$ cu ft of space.

I.B.M. United Kingdom

The IBM 650 computer system with magnetic tape, can be seen alternatively engaged on production control and mathematical and scientific work.

The IBM 305 RADAC data processing system handles large amounts of information in a simple way, all records relating to a single business transaction are automatically and immediately amended. The system can be interrogated for any one of the 10 million characters of information contained in its store.

Jenkins Fidgeon

Ancillary equipment for the safe storage of paper and magnetic tapes and punched cards. Dust-tight cabinets for magnetic tapes, steel cases for spool storage and multi-drawer cabinets for filing paper tapes.

Lamson Paragon

Continuous feeding of forms into a data processing output printer. The system permits multi-copies to be taken from automatic printers. The sets of documents can flow through the print-out machinery in steps synchronized with the output.

Leo Computers

Information on the company's services for industry and commerce. Within a few hundred yards of the exhibition hall there are two fully operational computers, LEO I and LEO II. Consultants, programmers and engineers on the stand will give information or discuss computer applications. The control desk and test rack of LEO equipment are on show. LEO is particularly suited to nuclear calculations by virtue of the large, rapid access store and the large backing store on drums. Calculations have already been carried out on behalf of C.E.R.N.

Metropolitan-Vickers Electrical

The Metrovick 1010 computer (shown as a scale model) is a fast transistorized computer for data processing and real-time process control; it is also capable of solving complex scientific and engineering problems. A novel feature is the data scanner, which transfers information between the magnetic-core store and all ancillary equipment. Another exhibit is the 950 electronic digital computer—an inexpensive transistorized general-purpose computer for solving a wide range of mathematical, scientific and engineering problems. Other exhibits include the Metrovick 960 paper tape reader and a centralized monitoring and control system, including analogue-to-digital conversion.

Mullard Equipment

Autoplot automatic, electronically controlled co-ordinate positioning machine for drilling, marking out, plotting or draughting operations on sheet metals. New high-precision measuring system for machine-tool control.

Mullard

Semi-conductors and valves designed specifically for computer work. New high-frequency power transistors, type OC23 and OC24, capable of providing 700mA pulses of a duration, for example, of 2 microseconds, with rise times of less than 0.5 microseconds. Gold-bonded germanium diodes for use with transistors in high-speed computing circuits. Mullard ferrite store system. Automatic equipment for the rigorous testing of magnetic memory matrices using Ferroxcube rectangular-loop cores.

Powers Samas

The Pluto electronic data processing system has been developed in conjunction with Ferranti. The Samastronic output printer will print 300 lines of 140 characters per minute.

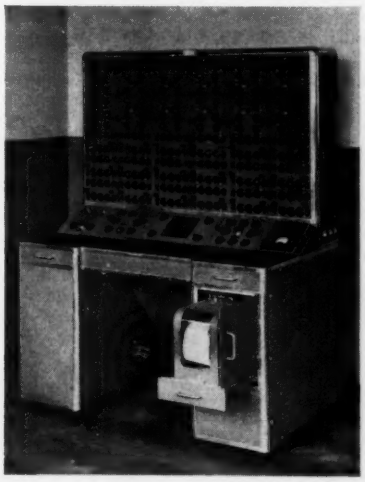
Plessey

New types of memory cores. Square loop ferrite cores for high-speed random access memories range in size from 0.05 in. to 0.375 in. Two special machines have been developed for testing. One of them individually inspects each core to prove its electrical characteristics and the other carries out automatic testing procedure on complete memory planes.

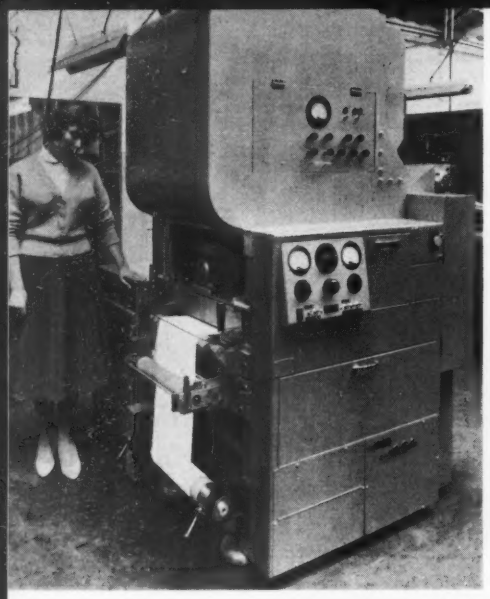
On the Plessey stand, Semiconductors are exhibiting high-frequency transistors for digital computer use.

Punched Card Accessories

Various methods of filing information sources so that they are quickly available. Simple and rapid means of transporting the necessary batches of cards or reels of tape from the library to the computer.



Short analogue computer for the solution of differential equations or for the simulation of actual physical systems.



High-speed output printing is obtainable with the new machine developed by Rank Precision Industries.

Rank Precision Industries

New type of output printer, still in the experimental stage. The model shown prints at 1,500 lines a minute, but the intention is to increase this to 3,000 lines a minute. By coded instructions fed to the computer, the layout of the final printed form can be predetermined. The system used is xerography—electronic printing without moving mechanisms.

Solartron Electronic Group

The Solartron electronic reading automaton, ERA, is shown as a production model for the first time. This machine can scan a page of typewritten figures and convert them into impulses so that written figures can be fed directly into data processing machines or computers.

SAKI (Solartron Automatic Keyboard Instructor) is the first of a family of electronic teaching machines. It enables punched-card operators to be trained very much more quickly than by conventional methods. The machine can also size-up the potentialities of a trainee very early in the instruction course.

Saunders-Roe

A system of using plug-in units to build up a complete computer. An amplifier mounting panel and five amplifiers allow an integrated piece of equipment to be set up, with the front of the panel forming the patch panel. The necessary control relays for the amplifiers are contained in the unit so that the panel and its amplifiers need only a power unit to become a complete analogue computer.

A " Miniputer " built in this form can be seen solving nuclear reactor simulation problems.

Short Brothers and Harland

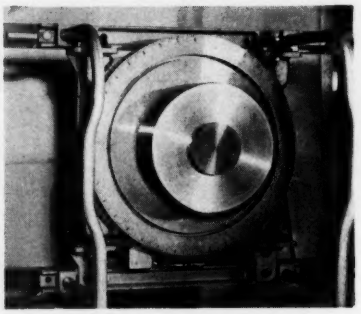
Exhibits draw attention to d.c. amplifier units designed to meet the needs of users who require only a small number of computing units to fit into an existing system or for universities and colleges which need a simple means of demonstrating analogue computing techniques. A time delay unit, designed primarily for problems associated with nuclear control, is also featured.

Nearly 50 of the Short general-purpose analogue computers are now in service at home and overseas. They are intended both for the solution of differential equations and the simulation of actual physical systems, and can be handled by an operator with no specialized electronic knowledge. The solution appears graphically, either on a cathode ray tube or as an inked graph on paper. For analysis of automatic control systems, Short are introducing a new instrument based on their low-frequency oscillator.

Southern Instruments

The K1028 trace reader which embodies the K635 unit, which is intended for reading oscillograph traces on film or paper up to 12 in. wide. Linear or non-linear calibrations may be introduced by means of calibration curves drawn on ordinary graph paper. The output, scaled in terms of the actual quantity represented by the trace deflection, may then be replotted in graphical form or digitized and displayed visually, tabulated by means of an electric typewriter, or punched on cards or tape.

(Right) High-precision magnetic storage drum by Sperry Gyroscope.



Sperry Gyroscope

A magnetic storage drum which Sperry developed in collaboration with Automatic Telephone and Electric for automatic telephone switching is capable of application to a much wider range of computer systems, particularly where high-density storage of information is called for. The design of the drum is based on marine gyro-compass techniques.

Standard Telephones and Cables

Main features of the Stantec-Zebra digital computer are the extreme flexibility of the programming method, the large memory store and the comparatively low cost of the machine.

EXHIBITORS AND STAND NUMBERS

Air Trainers Link, Ltd., Bicester Road, Aylesbury, Bucks. .. 1a

Benson-Lehner (G.B.), Ltd., 12 Bargate, Southampton .. 12

Boyden and Smith, Ltd., 147–150 Saffron Hill, London, E.C.1 .. 1

British Computer Society, Ltd., Finsbury Court, Finsbury Pavement, London, E.C.2 .. 41

British Olivetti, Ltd., 10 Berkeley Square, London, W.1 .. 42

British Tabulating Machine Co., Ltd., 17 Park Lane, London, W.1 .. 5 and 7

British Thomson-Houston, Ltd., New Parks Boulevard, Leicester .. 8

Bulmer's (Calculators), Ltd., Empire House, St. Martin's-le-Grand, London, E.C.1 .. 45

Burroughs Adding Machine, Ltd., 356–366 Oxford Street, London, W.1 .. 28

Creed and Co., Ltd., Telegraph House, Croydon, Surrey .. 30

Data Recording Instrument Co., Ltd., c/o British Tabulating Mch. Co., Ltd., 142 Park Lane, London, W.1 .. 25

Egry, Ltd., Warple Way, Acton, London, W.3 .. 3

Elliott Brothers (London), Ltd., Century Works, Lewisham, London, S.E.13 .. 35/43

E.M.I. Electronics, Ltd., Hayes, Middx. .. 26

E.M.I. Sales and Service, Ltd., Hayes, Middx... 33

English Electric Co., Ltd., Marconi House, Strand, London, W.C.2. .. 36

Fairey Aviation, Ltd., White Waltham Aerodrome, Berks. .. 43a

Fanfold, Ltd., 74–75 Watling Street, London, E.C.4 .. 17

Ferranti, Ltd., Hollinwood, Lancashire.. 10/14

I.B.M. United Kingdom, Ltd., 101 Wigmore Street, London, W.1 .. 34

Jenkins Fidgeon, Ltd., Meadows Road, Kidsgrove, Stoke-on-Trent, Staffs. .. 32

Lamson Paragon, Ltd., Paragon Works, London, E.16 .. 31

Leo Computers, Ltd., Elms House, Brook Green, London, W.6 .. 27

Logabax, Ltd., 21 Buckingham Palace Road, London, S.W.1 .. 46

London Office Machines, Ltd., Terminal House, Grosvenor Gardens, London, S.W.1 .. 44

Metropolitan-Vickers Electrical Co., Ltd., Trafford Park, Manchester, 17 .. 22

Mullard Equipment, Ltd., Mullard House, Torrington Place, London, W.C.1 .. 11

Mullard, Ltd., Component Division and Communications and Industrial Valve Dept., Mullard House, Torrington Place, London, W.C.1 .. 2

National Cash Register Co., Ltd., 206–216 Marylebone Road, London, N.W.1 .. 35/43

Neosid, Ltd., Stonehills House, Welwyn Garden City, Herts. .. 37

Panellit, Ltd., 70 Dudden Hill Lane, London, N.W.10 .. 49

Plessey Co., Ltd., c/o Roles and Parker, Ltd., 22 Red Lion Street, London, W.C.1 .. 6

Powers-Samas Accounting Machines (Sales), Ltd., Powers-Samas House, Holborn Bars, London, E.C.1 .. 10/14

Punched Card Accessories, Ltd., Abbey House, Victoria Street, London, S.W.1 .. 29

Rank Precision Industries, Ltd., 37–41 Mortimer Street, London, W.1 .. 48

Saunders-Roe, Ltd., Head Office, Osborne, East Cowes, Isle of Wight .. 19

Short Bros. and Harland, Ltd., Queen's Island, Belfast, Northern Ireland .. 4

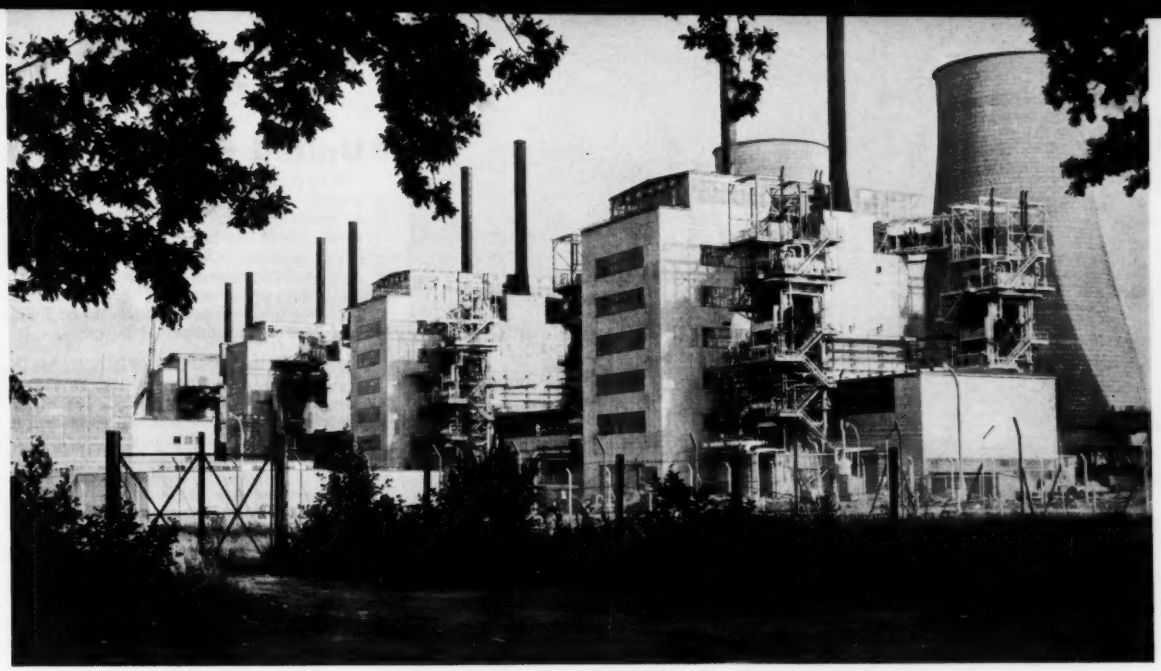
Siemens Edison Swan, Ltd., 155 Charing Cross Road, London, W.C.2 .. 16

Solartron Electronic Group, Ltd., Solartron Works, Thames Ditton, Surrey .. 9 and 18

Southern Instruments Computer Division, Frimley Road, Camberley .. 24

Sperry Gyroscope, Ltd., Great West Road, Brentford, Middx. .. 39

Standard Telephones and Cables, Ltd., 10 Essex Street, London, W.C.2 .. 23



First reactor at Chapelcross—Britain's second nuclear power station—went critical ahead of schedule on November 9. The reactor will be run up to full power progressively during the coming weeks.

World News

International

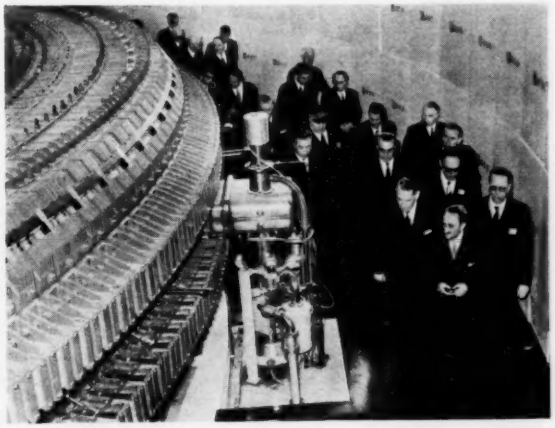
I.A.E.A. DRAFT MANUAL for Safe Handling of Radioisotopes will be published on December 5. The manual, which was drawn up by an international panel of experts, was approved by the Board of Governors at its meeting in October for provisional application to the Agency's activities. Eventually, a series of regulations and codes will be issued by the Agency; the manual will act as a guide in the intervening period.

EXPLORATORY I.A.E.A. mission left Vienna for Cairo on November 3. Members of the small team include Mr. B. V. Nevsky from the U.S.S.R. and Dr. V. Thayer from the United States. They will be accompanied by Mr. C. Beaumont, a member of the I.A.E.A. technical assistance division. This visit follows a request by Mr. I. Fahmy, Governor of the United Arab Republic, to provide information on the production of uranium from phosphate ores and heavy water.

BASIC STANDARDS for health protection against radiation have been submitted by Euratom Commission to the European Parliament. Once established these will be binding on all member States. Basic standards include: (a) maximum doses compatible with reasonable safety; (b) maximum permissible exposures and contamination: (c) the fundamental principle of medical supervision of nuclear workers.

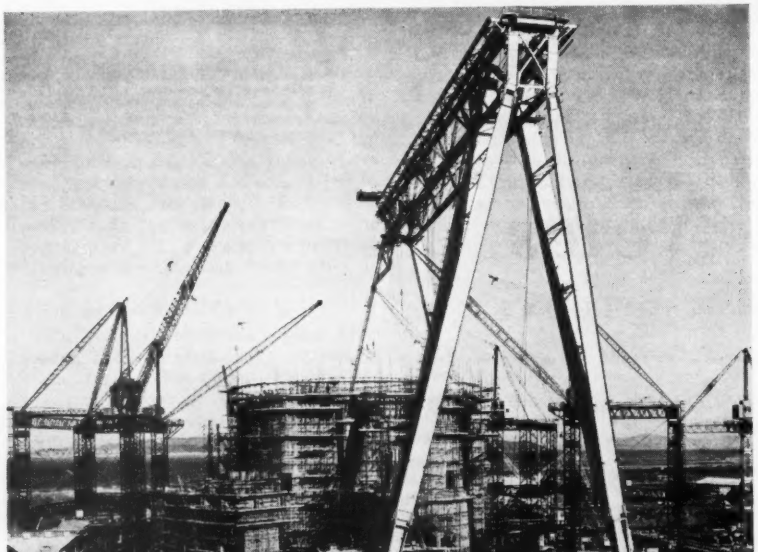
NUCLEAR co-operation agreement between the U.S. and Euratom has been signed in Brussels. This will mean that six to eight reactors based on American designs, are to be built in France, West Germany, Italy, Belgium, Netherlands and perhaps Luxembourg during the next five years. Capital cost will be in the neighbourhood of $350m. (£125m.) and about three-fifths of it will be borne by private utility undertakings. The U.S. Government will provide the rest in long-term payments. Euratom is to provide its own inspection system, to ensure the peaceful use of the fuel and material, in conjunction with the I.A.E.A.

SUITS filed by the French Government concerning U.S. patents were recently dismissed in Washington by the U.S. District Court. The two suits were filed by Commissariat a L'Energie Atomique, Jean Frederic Joliot-Curie, Lew Kowarski and Jean Henri Halban. It was attempted to reinstate a 1940 claim that the plaintiffs had discovered the principle of controlled nuclear reactions in 1939 that had been rejected by the U.S. Patent Office in 1940 on the ground that the application was based on abstract theory with no working details. The ruling is that Federal judges have no authority to order the Patent Office to reopen such a case.



Official visit of the French president, M. Rene Coty, to the new proton synchroton, Saturne, at Saclay. He was accompanied by M. Francis Perrin, High Commissioner for Atomic Energy.

(*Above*) HINKLEY POINT.—Although work has been in progress for less than a year 900 tons of reinforced steel and 22,100 yds. of concrete have been placed in the foundations and shield of No. 1 reactor.
(*Below*) HUNTERSTON.—The 300-ton Goliath, shown straddling No. 1 reactor building, has successfully completed its various tests.



(*Below*) BERKELEY.—As this recent photograph shows, excellent progress has been made at the A.E.I.-John Thompson site.

United Kingdom

WINDSCALE pile No. 2 will not be re-started. The A.E.A. have announced that it would cost £500,000 to do so, which would result in the plutonium produced being extremely expensive. The fuel will now be discharged and reprocessed for other uses and equipment will be, as far as possible, removed and certain of the buildings used for experimental purposes.

NUCLEAR POWER PROGRAMME. Replying to a question in the House on November 10, Mr. Maudling, Paymaster-General, said that it was still intended to complete between 5,000 and 6,000 MW of nuclear capacity in the U.K. by the end of 1966. He had been asked whether any modifications were likely to be made in the programme because of the falling capital cost of coal-fired power stations and the surplus of small coal.

NUCLEAR INSTALLATIONS (Licensing and Insurance) Bill, recently published, proposes that operators of nuclear reactors will be required to insure for liabilities of £5 million. Main purpose of the Bill is to control building and operation of nuclear reactors and other nuclear installations in the interest of public safety (see Editorial).

PUBLIC INQUIRY into the proposal by the Central Electricity Generating Board to build a 500-MW nuclear power station at Dungeness, in Kent, will be held at the Lydd War Memorial Hall on December 16.

Australia

URANIUM-BEARING mineral torbernite has been found in the Lake Boga area, near Swanhill, in northern Victoria. Preliminary examinations disclose that it is a promising discovery.

ENRICHED uranium, weighing 4½ kilograms, has been bought from the U.S.A. for $78,500. It will be used in the Lucas Heights research reactor near Sydney.

RUM JUNGLE mining operations have almost come to a standstill. The uranium lode has cut out but new deposits are expected to be found shortly.

Brazil

CONTRACT for the purchase of a Triga reactor has been signed by the University of Minas Gerais at Belo, Horizonte, with the General Atomic Division of General Dynamics Corp. Having a continuous power level of 30 kW and permitting intermittent operation at 100 kW, the reactor will be a below-ground-level type.

Belgium

TWO SUPPLY COMPANIES, the Societe Intercommunale de L'Escaut and the Societes Reunies d'Energie du Bassin de L'Escaut, have reached an agreement with the Dutch Provinciale Limburgse Electriciteit Maatschappij for the joint construction and operation of a nuclear power plant at Mol. It will be the first commercial reactor in the country and is scheduled for completion in 1963.

FORMATION of the Societe Anonyme Metallurgique et Mecanique Nucleaire has been registered with a capital of 100 million Belgian francs. It has been founded by the Fabrique Nationale d'Armes de Guerre and the Societe Generale Metallurgique de Hoboken to manufacture nuclear fuel.

Canada

PLUTONIUM FUEL ELEMENTS are operating in NRX on an experimental basis, the total charge being 5.4 kg as 20 elements. Irradiation has so far totalled 750 MWd; it is planned to continue to 2,000 MWd. A previous charge of 4.3 kg gave trouble after 600 MWd due to a sheath failure, necessitating a seven-week shutdown.

France

SATURNE, a new synchrotron, designed to impart energies of 2-3BeV to protons, thus creating special intranuclear reactions, has been inaugurated at Saclay nuclear research centre, near Paris. Under construction since 1953, it has cost about £6 million.

Germany

FOURTH research reactor in the country—a 1-5 MW swimming-pool type—has been opened in Geesthacht, near Hamburg. The reactor was supplied by U.S. Babcock and Wilcox and is for research into nuclear power for marine engines.

Italy

NATIONAL Association for the development of nuclear power for farming has been established in Rome.

FRASCATI National Laboratories have announced that the 1,200 MeV electro-synchrotron, first nuclear machine entirely built and designed in the country, has gone through initial stages of operation successfully.

FOUNDATION STONE of the 200 MW nuclear power station which is being built by N.P.P.C. at Latina was due to be laid on November 20.

Japan

LICENSING agreement for nuclear power equipment has been signed by Mitsubishi with Westinghouse Electric Corp. The technical details have been agreed upon, but await approval of the Government.

Netherlands

KEMA, of Arnhem, will open a new laboratory for nuclear research in which test with a suspension reactor will be undertaken.

New Zealand

EXTENT of uranium deposits will be investigated by an office of the United Kingdom A.E.A., to be opened soon, probably on South Island.

Norway

DIRECTOR of the Dutch-Norwegian Atomic Research Institute at Kjeller, Dr. Gunnar Randers, has announced that work will soon begin on a 3-million-kroner (£100,000) research project for a nuclear-powered tanker.

NORATOM have been asked by the Oslo Electricity Works to study the possibility of using nuclear back-pressure generating and heating for Oslo.

South Africa

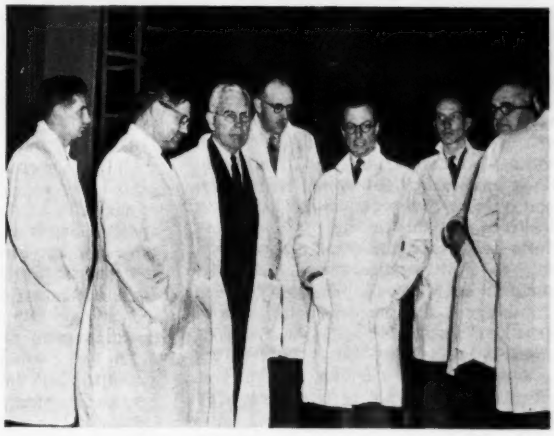
URANIUM OXIDE in concentrated form is to be sold to the Atomic Fuel Corporation of Japan. Initial sale will only be 6½ tons. This is the first sale over and above the 6,200 tons per year contract with the British and American Combined Development Agency.

Switzerland

FEDERAL RAILWAY have decided to participate in Suisatom A.G. who are building an underground nuclear power station at Bottstein-Mandach-Villigen, near Zürich.

SMALL thermonuclear explosions will be used by the United States for the creation of a small harbour and channel in Kotzebue Sound, near Cape Thompson, Alaska. The site has been chosen because it is particularly sparsely settled, but residents will be evacuated to at least 15 miles from the site

APPROVAL has been given by the United States for the construction of a nuclear power plant at McMurdo Sound in the Antarctic. Money has not yet been granted and total cost is expected to be between $4 million and $5 million.



Mr. John A. McCone, chairman, U.S.A.E.C., and Dr. Willard F. Libby visited nuclear installations in the U.K. early in November. They are seen here with a group of A.E.A. personnel inside the fast reactor sphere at Dounreay. (Left to right) Mr. Tatlock, Dr. Robert Hurst, Mr. John A. McCone, Mr. J. L. Phillips, Sir Edwin Plowden, Mr. Rawlinson, and Sir Leonard Owen.

United States

A.E.C. have issued licences to the following: Industrial Reactor Laboratories for the limited operation of a research reactor pending completion of tests of the reactor containment vessel; Allis-Chalmers for construction of an experimental nuclear reactor in Wisconsin; proposed issuance of licences to Oregon State College for operation of a low-power teaching reactor; National Aeronautics and Space Administration for a low-power reactor at the Lewis Research Centre, Cleveland.

AMENDMENT giving licence exemption to users of products containing low concentrations of radioisotopes has been proposed by the A.E.C.

PROPOSALS for the design, development, fabrication and installation of a factory-assembled, modular nuclear power plant, have been invited by the Air Force and A.E.C. The plant will have a pressurized water reactor, cooled and moderated by light water, and fuelled with enriched uranium. It is to be installed for electricity and heating for an Air Force base in the U.S. Proposals are also sought for a programme of research into fuel cycles.

CONSTRUCTION on a pilot plant for calcining high-level radioactive liquid waste products has been started at the National Reactor Testing Station in Idaho. Fluor Corporation will build the plant at a basic estimated cost of $3,391,700. Total estimated cost is stated to be $6 million. The waste calcination facility is designed to reduce high-level liquid radioactive wastes to safer and more storable liquids.

ADDITIONAL time for comment has been allowed by the A.E.C. on the proposed amendments to indemnity regulations. These relate to the rule which establishes the procedures under which the Commission will indemnify reactor operators up to $500 million against claims arising from accidents which exceed liability insurance coverage.

KEEL of a new nuclear-powered submarine has been laid in Portsmouth, New Hampshire. It will weigh 5,600 tons and will take about three years to build, and will be equipped with Polaris intermediate-range ballistic missiles. Cost is estimated to be £35 million.

EIGHTY-SIX BIDS have been received by the A.E.C. in response to the invitation for performance studies on three reactor concepts: 30 each for the BWR and the organic-moderated system and 26 for the PWR. Total number of proposals come from 32 architect-engineering concerns associated with 16 nuclear design companies.

INDUSTRIAL PARTICIPATION in atomic energy developments is to be evaluated by a statistical survey organized by the Bureau of the Census (Department of Commerce) in association with the A.E.C.

FIRST REACTOR of the two units comprising the prototype power plant for large naval surface ships went critical on October 21. Two ships now under construction are USS Long Beach (guided missile cruiser) and USS Enterprise (aircraft carrier).

U.S.S.R.

NEW REACTOR using uranium hexafluoride as both fuel and heat transfer agents has been designed by Academician Issac Kikorin.

Orbits in Industry

ANYONE who has read the article on page 515 of this issue should, by now, be rid of any optimistic ideas that the theory of shielding is simple. Let us whisper a word into your shell-like . . . neither is the practical side. According to a communication received from the Lead Development Association, the idea that lead shielding design is a jot for an intelligent schoolboy has been responsible for a great deal of extra trouble and expense to everyone concerned. First, those who design the shield frequently don't know much about lead technology, and imagine that because lead has a low melting-point the casting of it into any form is money for jam. Apparently, they couldn't be more wrong. Secondly, there is not very close liaison between the designer and the contractor, who is all too often chosen after the design is complete, and finds himself told to get weaving with a one-piece design that either cannot be cast or is unnecessarily expensive.

The answer appears to be to consult the Lead Development Association first. Just as the Radiological Protection Society will advise on the safety of your design, the L.D.A. keep a technical staff who will help you to avoid the snags, that cost so much not only in actual cash, but in time needlessly lost.

Lead Etymology

Query (inspired by above). What is the correct term for a one-piece construction in lead? In concrete, one talks about monolithic—would unoplumbic be all right for lead? (Mem. Ask the L.D.A. . . . preferably by 'phone . . . there's a long drop from those upper windows in Adam Street and we do, at least know the meaning of defenestration.)

Epicycling Tour

Two recent visits, while not directly connected with nuclear matters, have, nevertheless, proved more than interesting. First was the official re-opening of the Atlas Works at Pershore, which W. H. Allen Sons and Co., Ltd., have taken over for gear manufacture. The old Atlas Works used to make agricultural machinery in the long, long ago; its reconditioned buildings must rub their old eyes a little to see large double helical gears being shaved under temperature-controlled conditions—a process that can seldom have been necessary for the original 1 h.p. hayrakes and mangel-wurzel-fuddlers.

With memories of early motorcycles with hub gears (cycle gears were all right) the word "epicyclic" to Tangent has always conjured up a vision of a nickel-plated tin cylinder full of demented clockwork that presented considerable difficulty in the early stages of disassembly (due to the lack of special pin spanners) and finished the operation by itself with some species of minor internal explosion, scattering its vital organs around the landscape. The reality was rather different—a 5½-ton unit to drive a mine tunneller at 9 r.p.m. was capable of a maximum torque of 110,000 lb-ft, and looked it.

Unless someone decides to go in for geared blower drives—and the space saving with an epicyclic design is really spectacular—it is difficult to see what large epicyclic gears will have to do with the nuclear field. Nevertheless, it was from a personal point of view a very worth-while trip. It was good to see down to earth precision engineering for a change, using materials for their strength only and not worrying about neutron economy, poisoning, effect of irradiation or what have you.

There is just one suggestion that we would make, if the company decides to have many visitors, and that is the provision of Perspex models of the different types of gear and the different effects of fixing the sun wheel, the planet wheels or the annulus. Getting a mental picture of simultaneous happenings at three places in three dimensions at the same time is not the easiest thing in the world, and to judge by the number of persons scowling fiercely at an exhibit while their index fingers and heads waggled uncertainly in circles, our feeling of slight uncertainty is not unique.

Rings

The other visit, to see the official opening of the new ring mill at Hingleys Iron Works (page 542), impinges more directly on nuclear matters, since it seems to Tangent that those solid forged rings have an application in the expansion joints for high-pressure gas ducting and, for that matter, many other situations. Once again, it was good to see the teamwork, particularly amongst the hammer men. Nobody seems to do anything in the way of signalling; but everybody seems to realise exactly what is wanted.

The same applied to the actual ring rolling process. The only perceptible signal was that the gaffer held up his hand when the ring had been rolled to the right diameter, which he apparently judged by eye with some assistance from a chalk mark on the carriage, and the man in the control pulpit simply backed out the carriage and released the squeeze. Well realizing that the ring would be scrapped if the squeeze was kept on a fraction of a second too long, we were nevertheless bold enough to inquire in our best gaping-tourist manner. The rather pained way our question was answered, told us what we wanted to know. It just doesn't happen. This, presumably is just as well, a titanium ring recently rolled cost some £3,000.

Despite the modernity of most of the equipment seen, Noah Hingley, who was born in 1796, started the company in 1838, making chain cables and, later, anchors. He also must have been keen on new equipment because he had the first steam hammer in the Midlands—personally installed by James Nasmyth, at that time a rising lad of about 42.

The beam engine that used to drive the rolling mills has been scrapped—not without grief—but it was just too big to be left lying around the works and too big for a museum. On the other hand there is still at Hingley a Murray cycloidal engine which started life in another works at Stourbridge in 1802 and is still maintained *in running order* although it is found more convenient to use compressed air when visitors want to see the wheels go round. There is, apparently, only one other specimen known, and that is in the Ford Museum in Dearborn. Looking at this, it is not difficult to believe that the company has only had four chairmen in 120 years—they must be hand-forged, too.

DR. FINAGLE'S LAWS—6

Law of Connections

Only shop-riveted or welded connections will require alteration at site. Bolted connections rarely require it.

Only a Faded Memory!

Unutterably sad is the story of the "electronic brain" exhibited at Geneva, which has disappeared on the return journey. One can only assume that its memory-drum has become demagnetized. As the late Marie Lloyd might have sung:

My Sales Man.,
Said "Get in that van,
You're wanted by S.-I.-M.-A.";
Off went the van—but not me,
Misters
I'd rather trust to my own
transistors;
—It's too pathetic
Something magnetic
"Alcomax" or "Ticonal" or
chrome
Or the Al-Co-Nickel
Gave my drum a tickle
NOW I CAN'T FIND MY WAY
HOME!

Tangent

Personal

Mr. T. M. Fry.

Prof. P. Cerenkov.

Mr. J. A. Gay.

Appointments

Mr. J. A. Gay as patents exploitation officer to U.K.A.E.A.

Dr. T. E. W. Schumann as independent deputy chairman to the South African Atomic Energy Board.

Mr. J. R. Thomas and **Cdr. E. G. Sutton,** as directors of John Thompson (Wolverhampton).

Mr. W. F. Shaylor and **Prof. A. D. Baxter** to the board of directors of de Havilland Engine Co. Mr. Shaylor will also become sales director.

Dr. F. K. Pittman as director of A.E.C. division of reactor development, **Dr. A. J. Vander Weyden** as deputy director of the same division.

Mr. D. D. Angus as managing director (general division), **Mr. A. Proctor** as managing director (engineering division) and **Sir W. J. Drummond** as additional deputy chairman of George Angus and Co.

U.S.A.E.C. staff appointments include the following: **Mr. J. A. Hall** as assistant general manager for International Activities, **Mr. A. A. Wells** as director, Division of International Affairs, **Mr. C. V. Vogel** as deputy director of the same division, **Mr. J. L. McGruder** as director of the newly created Office of Plans, **Mr. D. A. Ink** as special assistant to the chairman, and **Mr. R. X. Donovan** as a special assistant to the general manager for Congressional Relations.

Mr. J. W. Plowman (Dewrance and Co.) has been re-elected as chairman, **Mr. N. P. Newman** (Newman, Hender and Co.) re-elected vice-chairman and **Mr. F. S. Ham** and **Mr. T. B. Pattison** as new committee members of the British Valve Manufacturers Association for 1958-9.

Above we reproduce a photograph of **Mr. T. M. Fry,** who, as recorded last month, is the new head of reactor division A.E.R.E., Harwell.

Mr. G. M. Baker as general manager of C. A. Parsons.

Mr. W. H. Stratford and **Mr. R. W. Brocklehurst** to board of directors of English Steel Forge and Engineering Corp.

Mr. P. Turrell to board of directors of English Steel Rolling Mills Co.

Mr. K. Chatterton, as chief engineer of English Steel Corp.

Captain G. Coles and **Cdr. C. Thomas** as directors of Webley and Scott.

Mr. O. S. Woods as controller of East Midlands division of the Central Electricity Generating Board.

Mr. A. R. Miller as chairman of Motherwell Bridge and Engineering. **Mr. F. D. Masterton,** secretary of the company also becomes a director.

Mr. R. Dawes and **Mr. J. E. Wall** as directors of Electrical and Musical Industries.

Mr. W. R. Grimes as director and **Mr. H. F. McDuffie,** assistant director to a new Reactor Chemistry Division of Oak Ridge National Laboratories.

Mr. J. N. Toothill and **Mr. J. H. Thomson** as a director of Ferranti.

Mr. W. M. Tulip as regional secretary of the North-Eastern and Yorkshire region of the Central Electricity Generating Board.

Mr. Strauss, former chairman of A.E.C., as Secretary of Commerce in Washington.

Hyman C. Rickover to rank of vice-admiral, United States Navy.

The Hon. J. Geddes has assumed responsibility for public relations for the Elliott-Automation Group.

Mr. G. C. R. Eley to the board of directors of British Oxygen.

Mr. R. C. Agabeg as assistant sales manager of chemicals division of Union Carbide.

Mr. D. J. Davis as sales manager of British Physical Laboratories.

Mr. V. D. Swain to assistant superintendent control department of Metropolitan Vickers.

Mr. G. F. W. Adler as chief mechanical engineer and a member of the directorate of engineering, Marconi Wireless Telegraph.

Mr. L. Sultan as group public relations officer, **Mr. K. E. Shurley** deputy group publicity manager and **Mr. J. C. Edmunds** as assistant publicity manager of C. C. Wakefield.

Mr. F. N. Sutherland as managing director, Marconi Wireless and Telegraph and director of Marconi Instruments. **Mr. P. de Laszlo** as director of Marconi Wireless Telegraph and Marconi Instruments.

Mr. S. C. Heward to manager, Associated Companies Division of Marconi and **Mr. G. T. Kelsey** as manager of the London office.

Mr. G. L. Ball as general sales manager of Wayne Kerr Laboratories.

Mr. K. P. Källgren as manager of Solartron Electronic Group's new branch in Sweden.

Mr. R. Yeoman, general manager of Hodgkinson Group to the board of A. B. Scorer, a subsidiary company.

Lieut. Cdr. J. Tinneveld to the board of directors of Cockburns.

Mr. J. N. B. Alexander and **Mr. S. W. Kaye** as joint managing directors (Sales) of Stewarts and Lloyds.

Mr. N. McCann as secretary and director, **Mr. R. G. J. Nisbet** as director of Canadian Operations, **Mr. J. A. Jackson** as works director and **Mr. W. N. Scottorn** as sales director of Wolf Electric Tools.

Mr. L. R. Evans to board of directors of English Steel Casting Corp.

Mr. R. Fielding to board of directors of English Steel Spring Corp.

Mr. Francis K. McCune, general manager, General Electric atomic products division, as president, Atomic Industrial Forum.

Mr. G. L. Ball.

Mr. W. F. Shaylor.

Prof. A. D. Baxter.

Sir John Cockcroft, A.E.A. member for research, and four members of the U.K. thermo-nuclear research team left London Airport on November 8 for a visit to the U.S.S.R. to study Soviet thermo-nuclear work. Members of the U.K. team were Dr. P. Thonneman, Dr. R. J. Bickerton, Dr. W. B. Thompson and Mr. R. S. Pease. Later Sir John and Mr. Peter Mummery visited Tokyo for talks with the Japan Atomic Energy Commission and other organizations interested in nuclear energy in Japan.

Mr. C. F. Saunders, as chief engineer, standards department; **Mr. G. H. Moule** as chief engineer, heating and welding department; **Mr. R. F. Mansfield,** A.M.I.E.E., as assistant sales manager, industrial control department and **Mr. F. Crowther,** as assistant chief engineer industrial control department, Metropolitan-Vickers Electrical.

Mr. D. E. Burton as head of London Technical sales department of Rocol.

Mr. J. Richmond as divisional executive and sales manager (Rugby), **Mr. J. W. Ward** as assistant sales manager (Rugby), **Mr. D. R. S. Turner** as divisional commercial manager, **Mr. R. R. Whyte** as divisional manufacturing manager, **Mr. W. T. H. Golding** as works manager and **Mr. R. O. Knight** as superintendent of Larne Works, A.E.I. Turbine Generator Division.

Also **Mr. H. I. Wood** as chief engineer, Turbo-Generator Dept. (Trafford Park), **Mr. F. R. Harris** chief engineer gas turbine Eng. Dept., **Mr. F. W. Craven** as superintendent, Small Turbine Dept., and **Mr. J. B. P. Wood,** assistant superintendent, Small Turbine Dept. of A.E.I. Turbine-Generator Division.

Awards

Professor P. Cerenkov, Doctor of Physics and Mathematics, **Ilya Frank,** corresponding member of the U.S.S.R. Academy of Sciences and **Igor Tamm,** a member of the Academy, the Nobel Prize for physics for discovering and explaining the Cerenkov effect.

Dr. Eugene Wigner of Princeton University the third Enrico Fermi Award for his numerous contributions to the developments of nuclear recators.

Retirements

Mr. John Taylor, deputy works manager of the British Insulated Cables' Leigh Works after almost 51 years' service.

Tours

Mr. J. A. McCone, chairman of the A.E.C., and **Dr. W. F. Libby,** a member, are at present touring the United Kingdom discussing the agreement for co-operation between the two countries with British leaders.

Mr. B. N. Reavell, deputy chairman and joint managing director of Kestner Evaporator and Engineering to Australia for about four weeks.

Obituary

Nuclear Engineering record with regret the deaths of the following personalities:—

Mr. E. J. Waddington, a director of Vickers and Vickers-Armstrong, on November 9 at the age of 64. Mr. Waddington joined Vickers in 1920 and was appointed to the board of directors in March, 1950.

Mr. B. E. G. Forsling of B.T.H. Turbine Eng. department on October 23 at the age of 58. Mr. Forsling has been a manager of the engineering department in Rugby for the past eight years.

Mr. A. S. Dodds, a director and London manager of John Thompson Water Tube Boilers on November 4.

Industrial Notes

Vitro Laboratories, a division of Vitro Corporation of America, have been awarded a contract to investigate the chemistry of long-lived radioactive fission by the Atomics Energy Division of Phillips Petroleum.

S.I.M.A.—the Scientific Instrument Manufacturers' Association—held their annual convention at Harrogate early in November. For the first time instrument equipment users were invited to exchange views with instrument manufacturers. Following the discussions plans are being formulated to develop this instrument user/manufacturer liaison through the Engineering Equipment Users Association.

Spembly have recently formed a nuclear energy division with Mr. A. C. Thorne, as manager. The expansion is coupled with a building project to provide space for nuclear assembly work.

Elliott Bros. (London) have been awarded a contract by the Central Electricity Generating Board for the design and manufacture of a nuclear power station simulator. It will be used for training operators for the Berkeley and Bradwell power stations and for future stations of similar type. The simulator will be installed at Berkeley mid-1959.

Internuclear Company has been retained by the Japan Atomic Energy Research Institute to provide consulting engineering services. Technical assistance in preparing specifications is being provided in connection with the Institute's plan to purchase a demonstration reactor. Mr. Lawrence C. Widdoes, vice-president, and Mr. Carl F. Leyse, technical director of Internuclear, have just returned from a visit to Tokyo for technical discussions about the project.

W. H. Allen Sons and Co., Ltd., held an official re-opening of their Atlas Works at Pershore, in late October. Atlas Works, once devoted to agricultural machinery, was acquired by Allens in 1955 and has been modernized throughout and equipped with precision machinery for the production of gears of both parallel-shaft and epicyclic types, notably the Allen-Stoekicht double helical epicyclic type, which form the major portion of their present gearing production.

Part of the gear-cutting department in the Atlas (Pershore) Works of W. H. Allen Sons and Co.

The U.K.A.E.A. has announced contracts for the Advanced Gas-cooled Reactor project at Windscale (*Nuclear Engineering*, Oct., '58, p. 431). These include: pressure vessel, Whessoe; turbo-alternator and associated equipment, English Electric; heat exchangers, International Combustion; incorporating welded helical high-fin tubing, Tube Products Ltd.: beryllium, I.C.I. (fabrication into tubes will initially be done at Springfields); containment building, Babcock and Wilcox; dump condenser, Hick Hargreaves; feed pumps, Mather and Platt; building and civil engineering, Whatlings. Ewbank and Partners have been retained as consultants for the turbo-alternators and that part of the steam plant within the turbine hall.

Vagnone and Boeri of Corso re Umberto 18, Turin, have been appointed agents for Martonair pneumatic equipment in Italy.

The Newmarket Transistor Company, the Pye group's transistor subsidiary has changed its name to Newmarket Transistors.

T.I. Technological Centre has now been operating its experimental beryllium tube fabrication laboratory at Walsall for six months. AGR type element tubing (0.3 in. i.d., 0.04 in. wall) has recently been cold bent on a 5-in. radius.

Central Electricity Generating Board have announced their tariff for bulk supplies to be sold to the Area Boards beginning April, 1959. The revenue yield will be substantially the same but the make-up shows significant changes.

The bulk supply tariff from 1959/60 is made up of a maximum demand charge of £7 2s. per kilowatt and a running charge of 0.41d per unit. Coal cost adjustment of the running charge has been reduced to 0.00055d (compared with 0.0006d) for each penny by which the fuel cost per ton in the year shall be below 60 shillings.

Tracerlabs reactor monitoring centre in Richmond, California, is building two retention tank monitoring systems for the Instituto Venzolano de Investigaciones Certificos, in Caracas, Venezuela. They will be used in the Institute's new research reactor and laboratories now being built in Caracas.

Atomics International, a division of North American Aviation, announces the opening of new headquarters in Canoga Park, California. Completion of the new centre is expected to be late 1959.

General Electric Company have bought a Pace analogue computer from the European Division of Electronic Associates, of Brussels. The equipment, which will be used by G.E.C.'s Atomic Energy Division, Erith (Kent) contains high accuracy linear and non-linear computing components, modular patch panel and the new Aero system which automatically scans all elements and prints digital results at 200 characters a minute.

Kelvin and Hughes (Aviation) have recently opened new premises in Barkingside, Essex.

English Electric have reduced prices of two motors in the Class "LY" and the Class "C" ranges of squirrel-cage designs.

Associated Electrical Industries have moved to new offices at 33 Grosvenor Place, London, S.W.1. Other A.E.I. companies who have moved to the same address include A.E.I.-John Thompson Nuclear Energy and B.T.H. Export. New telephone number is Belgravia 7011.

Lancashire Dynamo and Crypto have announced price reductions in their "Fankuld" range and Ventilated types up to 50 h.p.

Gresham Developments have moved to Thurlestane House, Uxbridge Road, Hampton Hill, Middlesex.

Simon-Carves offer to acquire the issued capital of Lodge-Cottrell, manufacturers of electro-precipitation plants, has been accepted.

General Dynamics Corporation are to install a TRIGA reactor at the University of Lovanium, Leopoldville, in the Belgian Congo. The reactor, recently on display at Geneva, will be shipped and reassembled by the company's General Atomic Division.

Thomas Marshall and Co. (Loxley) have acquired the half interest previously held by the Morgan Crucible Co., Ltd., in Carblox, which has become a wholly owned subsidiary of Marshalls.

20th Century Electronics have opened a new extension to their main factory at New Addington. It will house control equipment for the stable isotope distillation columns erected by the company. The columns are being operated as part of a ten-year agreement with the U.K.A.E.A.

Vickers Research has been registered as a private company with a nominal capital of £100. It will conduct and facilitate research connected with any business or project carried on by the Vickers group.

Dewrance and Co. announce that their sole representative for Northern Ireland is Mr. Duffin McNeice, 87 Rochester Avenue, Cregagh, Belfast. Tel. Belfast 48823.

Solartron Electronic Group have concluded selling and manufacturing licensing agreements for the "Kintel" range of electronic products of The Cohu Electronics, Inc., of San Diego, California.

Foxboro-Yoxall have opened a training school for industrial control instruments at their new Redhill factory.

Hollerith (East Africa) is the latest of the six overseas subsidiary companies of British Tabulating Machine. This new company has taken over existing business in Kenya, Uganda, Tanganyika and Zanzibar. Mr. G. C. Reed is chairman of the new company.

U.K.A.E.A. have commissioned two six-foot high stone figures by Ophelia Gordon Bell to be erected at the entrance to the Engineering block of the A.E.A. Industrial Group headquarters at Risley, Lancashire.

Sylvania-Corning Nuclear Corp. have announced completion of more than 5,000 advanced-design fuel elements for Brookhaven National Laboratory research reactor.

Lightfoot Refrigeration and Gesellschaft Fur Linde's Eismachinen of Wiesbaden (West Germany) have signed an agreement for exchange of technical resources for refrigeration and air conditioning plant.

Cape Asbestos have bought the whole of the share capital of Consolidated Blue Asbestos Corporation (Pty.), a company with blue asbestos mines in Cape Province, South Africa.

Can-Met Explorations is now treating 3,000 tons of uranium ore daily at its Quirke (Lake Ontario) plant.

Meetings

December 2—Institution of Electrical Engineers (C.E.G.B. Offices at Leeds). "Operational Experience at Calder Hall," K. L. Stretch.

December 2—Institution of Chemical Engineers (North-Western Branch, Chemical Engineering Building, Manchester College of Science and Technology, Jackson Street, Manchester). "Wetted Area in Packed Towers," W. S. Norman and B. Solomon.

December 2—Institution of Electrical Engineers (Engineers' Club, 17 Albert Square, Manchester). "Thermonuclear Fusion and the Development of 'Zeta,'" E. R. Hartill.

December 2—Institution of Electrical Engineers (City of Birmingham Town Hall). Faraday lecture on "Automation," H. A. Thomas.

December 2—I. o. Welding—Slough section (Lecture Hall, Community Centre, Farnham Road, Slough). "Welding in Nuclear Engineering," A. Prince.

December 4—The British Institution of Radio Engineers (Reynolds Hall, College of Tech., Sackville Street, Manchester, 1). "High Input Impedance D.C. Amplifiers," S. Stuart.

December 4—Institution of Electrical Engineers (in coniunction with the British Nuclear Energy Conference). "A Review of Work towards Nuclear Energy from Controlled Thermonuclear Reaction," D. W. Fry.

December 4—Society of Chemical Industry (Chemical Eng. Group) (Chemical Dept., University of Bristol, Woodland Road, Bristol). "Titanium and its Alloys as Materials of Construction for Chemical Plant," Dr. K. W. J. Bowen.

December 8—Institution of Electrical Engineers (Joint Meeting with the Supply and Utilization Groups at the University Engineering Labs., Bristol). "Operational Experience at Calder Hall," K. L. Stretch.

December 9—Society of Chemical Industry (Chemical Eng. Group). "Some Aspects of Radiation Induced Chemical Processes," Dr. R. Roberts.

December 10—Institution of Marine Engineers (Institution of Engineers and Shipbuilders in Scotland, 39 Elmbank Crescent, Glasgow, C.2). "Some Considerations Influencing Ship Nuclear Installations," by R. Y. Bell.

December 10—Institution of Electrical Engineers (Rugby College of Technology and Arts). "Recent Uses of Ultrasonics in Investigating the Characteristics of Materials," J. Lamb.

December 11—Institution of Electrical Engineers (Joint meeting with the Yorkshire branch of the Institution of Mechanical Engineers at Leeds University). "Modern Re-heat Practice in Steam Power Stations," F. H. S. Brown and J. W. H. Dore.

December 11—Institution of Electrical Engineers (Conference Room, S.W.E.B. Showrooms, The Kingsway, Swansea). "Operational Experience at Calder Hall," K. L. Stretch.

December 11—Institution of Electrical Engineers (Electrical Eng. Dept., Queen's College, Dundee). "Electrical Installation at Calder Hall Nuclear Power Station," N. J. Mackay and E. Hardwick.

December 12.—Institution of Electrical Engineers (Robert Gordon's Tech. College, Aberdeen). "Electrical Installation at Calder Hall Nuclear Power Station," N. J. Mackay and E. Hardwick.

December 15—Institution of Electrical Engineers (King's College, Newcastle-upon-Tyne). "Magnetic Tape for Data Recording," C. D. Mee.

December 16—Institute of Metals (Dept. of Metallurgy, University College, Singleton Park, Swansea). "Properties of Metals at very low Temperatures," by J. E. Aubrey.

December 16 and 17—Institute of Metals (Church House, Great Smith Street, S.W.1). Symposium on the Powder Metallurgy of Ceramic Metal Materials.

December 17—Institution of Chemical Engineers (The Geological Society, Burlington House, W.1). "Liquid Distribution in Grid Packings. Parts I and II," J. W. Mullin.

Processes and Equipment

For further information on any item please enter the relevant number on the Reader Service Card enclosed with this issue and forward the card to the address given.

Welding Boilers on Site at Hunterston

A complete automatic welding installation by Quasi-Arc is now in operation on site at Hunterston nuclear power station. The 16 heat-exchanger vessels which are being fabricated on site by Motherwell Bridge are cylindrical pressure-tight containers which, when erected, will be 73 ft 6 in. high and 19 ft 6 in. in diameter. They will weigh over 200 tons..

In a large, fully equipped welding shop each vessel is built up from six strakes, plus a top and bottom head and a supporting skirt. A strake comprises three shaped plates. All internal and external seams, longitudinal as well as circumferential, are automatically welded by Quasi-Arc equipment. The design of an automatic welding installation on this scale, especially when all welds have to be of the highest possible quality, has presented many problems; special machines have been produced to meet the exacting requirements.

The workshop area is divided into two bays, each serviced by an overhead 40-ton crane. Among the operations carried out in the first are the setting-up and tack-welding of the strakes and the top and bottom heads. The strakes are then moved to the second bay which has two parallel sets of rails running down its length. It is in this bay that the main automatic welding operations are performed. The longitudinal seams in the strakes are first welded with a traversing and swivelling welding boom, the largest of its kind in the world, each strake being supported on one of the 40-ton roller-beds. The strake then passes via turn-tables to the next set of rails for circumferential welding. For this purpose, a second and somewhat smaller traversing welding boom is used, running on a separate track alongside the roller-bed track. At the same time the swivelling boom, which runs on the first set of roller-bed tracks, can be turned through 90° and also brought into use over the second set of rails.

As the cylindrical vessel is built up it is X-rayed at every stage, holes are machined and nozzles and branches fitted; the complete shell is stress-relieved and hydrostatically tested, and finally the assembly is treated in a clean condition chamber and dry-sealed ready for erection.

All welding is carried out by the Unionmelt process, using a total of four Quasi-Arc multi-power D.S.H. welding heads, mounted on two traversing raise-lower booms, two heads to a boom. With this method two wires are used, each operating independently, having its own power source, feed motor, voltage control and nozzle assembly. Both wires are fed into a common weld pool. The current and arc voltage can be adjusted separately for each wire, allowing great flexibility in adjusting weld shape and penetration to obtain the best results at maximum welding speeds. Current is supplied by two Quasi-Arc transformers in Scott connection giving a maximum total current of 2,000 amp. Welding speeds obtained with the multi-power Unionmelt process can be more than twice those obtained with single-wire welding.

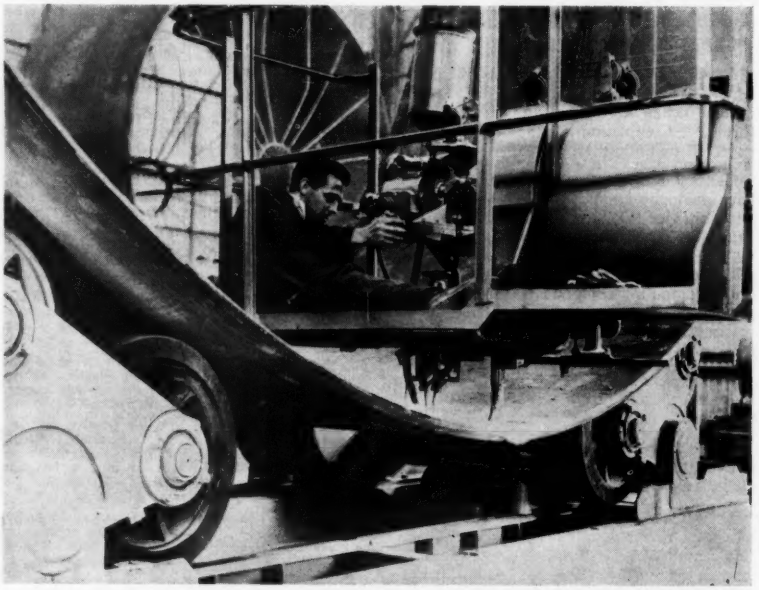
Both booms traverse on rails, the welding speed being variable from six and 60 in. per minute, with a high-speed traverse of 20 ft per minute for rapid positioning. Welding controls located on the welding head govern all functions of both the boom and the traversing roller beds supporting the section being welded.

The smaller of the two booms, intended for external welding, normally operates at right angles to the axis of the section welded, running on rails parallel to the roller bed rails. The other boom, in order to give the whole installation maximum flexibility, travels on the same rails as the roller beds and is arranged to swivel through 360°; it can weld both internally and externally, the maximum length of internal weld being approximately 22 ft. External welds on vessels of somewhat over 20 ft in diameter can be achieved with both booms. Again, for purposes of flexibility, remote control of all manœuvring operations, but not of welding conditions, is provided on the bogie of each boom. Ten roller-bed units are provided in the installation, each of which can support up to 40 tons, with a maximum of 20 tons/ft eccentric loading. Vessels with a maximum diameter of slightly more than 20 ft can be accommodated. All 10 units are drive units for both rotation and traverse; in the case of rotation, driving power is applied to both sides of the bed.

The vessels to be welded are supported on special rubber-tyred wheels to ensure good grip and even load distribution. The carriage supporting the pairs of rolls incorporates special pre-loaded rollers (which are the subject of a patent application) to enable them to be easily moved to accommodate vessels of different diameters when the bed is unloaded. Each roller bed can be operated as a separate unit, or any number can be ganged together and will then operate as a single unit. Power supply for rotation and traverse of the roller beds is variable D.C. supply obtained from A.C. via a grid-controlled Thyratron circuit. This arrangement facilitates ganging, which can be carried out simply by connecting a plug on one bed to a socket on the next. Each roller bed has a safety trip switch in case of overload; when a number of beds are ganged together, operation of the trip in one of them will stop the whole gang, but an indicator light will tell the operator which bed has the fault.

An unusual feature of the site welding shop is the transportation bogies which are an integral part of the installation. After welding and radiographic examination is completed, the heat-exchanger vessels are loaded on to a set of four bogies. They are then transported to the stress-relieving area, where they are given a 4-in. heat-insulating lagging. Hot gases are passed through the vessel for stress relieving.

Subsequently, the vessels are filled with water for pressure testing. The weight of a vessel so filled is approximately 1,200 tons. Under this load, the weight is not supported on the wheels of the bogie, but on special pads. A rubber mounting between the support cradle and the track wheel frame ensures equal load distribution. When carrying loads of up to 300 tons, the bogies can readily be moved by such as a capstan or tractor. *(Quasi-Arc, Ltd., Bilston, Staffs.)* **1152**



Close-up of the Unionmelt multi-power welding head and part of one of the Quasi-Arc 40-ton roller beds at Hunterston.

New Diaphragm Valves

Stainless steel diaphragm valves are now being made by Scotts Engineering, manufacturers of the Pearson-Scott diaphragm valve. The new units have bodies and bonnets of nickel chrome S.S. with a moulded, corrosion-resistant plastic handwheel. A Fluon membrane forms an integral part of the moulded diaphragm which is designed to give the maximum amount of resilience during the operation of the valve.

The valves are precision made under strict inspection conditions, with the result that only a small operating force is necessary to effect complete closure. Pipe connections are normally standard female taper gas threads but special fittings can be supplied. In standard form the units are suitable for pressures of up to 250 p.s.i. at temperatures of 150°C.

Following stringent tests the U.K.A.E.A. have placed a contract for a quantity of the valves in ¼-in. and ½-in. sizes for use in chemical plants processing radioactive material.

(Scotts Engineering (Newport), Ltd., Stafford Road, Newport, Mon.)

1153

Windowless Flow Counter

The windowless flow counter WF2, introduced by 20th Century Electronics has been designed for routine counting applications where large numbers of solid samples of low energy β-emitting isotopes such as carbon-14 or tritium are employed. The WF2 consists basically of a counting chamber beneath which is mounted a rotating sample holder holding three samples. Each sample is treated in the following way: (a) The sample on a suitable planchet is loaded on to the rotating sample holder. (b) The holder is rotated into a position where the gas flowing from the counting chamber flows across the sample to expel any air or vapours. This process is known as pre-flushing. (c) The holder is then rotated to bring the sample into position under the counting chamber and the measurement is made. A further rotation of the holder permits the sample to be changed. The next sample is thus being pre-flushed whilst counting is taking place.

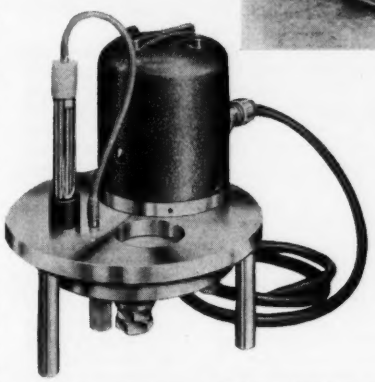
The principal advantage of this type of instrument is the increased counting efficiency due to improved sample counter geometry, and the lack of window absorption. This increased counting efficiency also enables more rapid counting of samples due to the shorter counting time required for a given accuracy. Counting chambers are available for proportional or geiger counting. Proportional counting is used for the assay of α-emitting substances and enables excellent discrimination to be obtained between α and β radiation. A gas mixture of argon-methane is employed at a flow rate of 0.25-0.5 litres/min. The operating voltage range for α-counting is 700-1,000 V and for β-counting 1,100-1,500 V.

Used as a geiger counter, commercially available gas mixtures such as "Q" gas may be employed, or alternatively a suitable mixture can be produced by bubbling commercial purity argon through ethyl acetate maintained at 0° C. The operating voltage range is 2,000-2,500 V. The efficiency of the counter for carbon-14 is 16%.

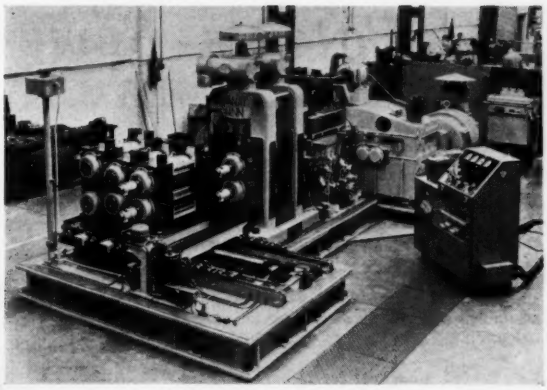
(20th Century Electronics, Ltd., Centronics Works, King Henry's Drive, New Addington, Croydon, Surrey.)

1154

(Below) Windowless flow counter, WF2 by 20th Century Electronics.



(Right) General view of the new Stanat-Mann mill from roll-changing end, showing roll magazine and hydraulic traverse.



Plutonium Rolling Mill

The small 2-high/4-high rolling mill for the accurate working required in the production of fuel elements and general experimental work has already been dealt with (*Nuclear Engineering*, November, 1956, p. 342). Further developments for enclosure of this type of mill, suitable for operation with alpha-active materials such as plutonium, have also been described (*Nuclear Engineering*, August, 1958, p. 339).

A new mill recently completed by Albert Mann's Engineering Co., Ltd., for the Commissariat a l'Energie Atomique of France represents an advance in two directions; one the actual size of the mill, which is considerably heavier than previous units, and the other, the use of automatic roll changing.

The mill itself is a Stanat-Mann 14-in. wide unit, with a maximum rolling load of 600,000 lb at a speed of 100 ft/min. The main drive is by a 100 h.p. motor with Ward Leonard control. The roll screwdowns are operated by a 2 h.p. infinitely variable speed motor through double-worm reduction, with magnetic clutches for independent adjustment of each side of the roll. Both main and screwdown motors are arranged for operation outside the glove-box enclosure which normally surrounds the mill.

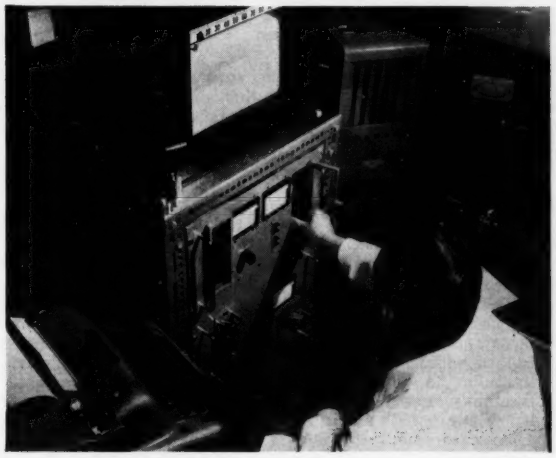
Roll changing is electro-hydraulically carried out, by remote push-button control. The sequence of operation involves: (1) disconnecting the screwdown from the top roll; (2) elevating the screwdown to a position which will accept any roll configuration; (3) withdrawal of the jibs retaining the chocks in position in the mill housings; (4) withdrawal of the roll assembly on to the roll carriage; (5) support of the universal spindles whilst withdrawing the roll assembly; (6) indexing of the roll carriage to line up the new roll assembly selected; (7) adjustment of the universal spindles to cater for the roll centres of the selected roll assembly; (8) entry into the mill of the new roll assembly; (9) locking into position of the chocks by the jibs; (10) collection of the new top roll assembly by the screwdown mechanism, with prevention of screwdown pressure being applied, when there is no material between the rolls.

The control equipment is based on a new technique of pulse controlled thyratons.

The instrumentation allows left hand or right hand roll pressure or the sum of both to be read at the control desk. Measurement can also be made of the neck torques of both rolls.

(Albert Mann's Engineering Co., Ltd., Basildon Industrial Estate, Essex.)

1156



Development model of data-handling equipment for faulty fuel elements at Hinkley Point (Marconi Instruments Ltd., St. Albans).

Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. 6d. each (including postage).

B.P. 794,671. Bonding of zirconium to other metals. K. F. Alder, M. L. Noakes. To: U.K. Atomic Energy Authority.

A sheath of zirconium or zirconium alloy is bonded to a core of fissile-bearing metal or alloy by hot-rolling at 550-650°C. The sheathed core is encased in copper and the assembly evacuated before rolling to prevent oxidation.

B.P. 794,761. Couplings for vacuum insulated pipelines. P. M. C. Lacey. To: U.K. Atomic Energy Authority.

The pipelines for liquefied gas have spigot and socket joints, but make contact only through a (rubber) sealing ring so that an annular space remains between spigot and socket forming a pocket in which the liquid conveyed tends to boil. This boiling liquid forms an insulating gas seal.

B.P. 794,834. Process for the separation of gaseous or vaporous substances, more especially isotopes. E. W. A. Becker (Germany).

The mixture to be separated issues from a nozzle-like opening in the form of an expanding jet. The jet is separated by an apertured diaphragm in its path into a peripheral portion and a core portion the latter passing through the aperture. A mixture of 98.5 mol% of hydrogen and 1.5 mol% of deuterium was subjected to the process using a nozzle of 0.47 mm smallest diameter and a conical diaphragm with an opening of 2.2 mm spaced from the nozzle opening 3.1 mm. The pressure was 15 mm Hg ahead of the nozzle. In the chamber around nozzle mouth and diaphragm the pressure was 2×10^{-2} Hg and in the chamber behind the diaphragm 1×10^{-2} Hg. The separation factor A was 1.37−0.02. (Separation factor $A=Nh(1-Nv)/Nv(1-Nh)$ where Nh is the molar fractions of the component with the higher molecular weight behind (h) and in front (v) of the diaphragm in the direction of flow.)

B.P. 794,901. Tubular fuel elements for nuclear reactors. H. Lloyd, A. Blainley. To: U.K. Atomic Energy Authority.

The fuel elements as rods or bars are longitudinally arranged in a circle within the wall of an encasing tube. A beryllium tube, e.g., provided with longitudinal bores receives uranium rods in these bores which are then closed by beryllium plugs welded to the wall by argon arc welding. Other closing methods may also be used. Sodium or its alloys may be introduced as an intermediate heat transfer medium.

B.P. 794,981. Retaining devices for fuel elements in gas-cooled nuclear reactors. G. E. Robinson. To: U.K. Atomic Energy Authority.

Gas pressure may expel fuel elements from the horizontal coolant channels. Then a new string of elements has to be introduced and the discharged elements have to be reprocessed. In order to prevent this happening, retaining devices are attached by a coupling at one end of the coupled string of fuel elements and hooks at the other end engaging the face of the reactor core. The hooks are in the form of pivoted cranks with a locking member to lock them in position. These members can be unlocked to release the cranks from their engagement with their reactor core.

B.P. 795,007. Method and plant for recovering the heat produced by chemical, physico-chemical and physical reactions. To: Electricité de France—Service National (France).

In nuclear reactions, cooling fluid may take part in the reaction and an efficient recovery of the heat carried along is obtained only by using as an operative fluid a condensable fluid (steam). In the path of the cooling fluid is inserted a steam generator or several generators which produce steam at different pressures fed to separate turbines or turbine stages. It means in any case considerable losses and/or intricate conduit arrangements. Now it has already been proposed, in French P.No.1,085,116 of Electricité de France, to follow up the transfer of the coolant heat to water with the transformation of the heated water into saturated or superheated steam by an auxiliary source of heat (fuel in a firebox of a boiler). The new method consists of the transfer of at least a fraction of the heat to be recovered to water under pressure, a fraction of which is transformed into steam by pressure reduction, the steam then being superheated by the heat in another fraction of the water. The energy of the steam is finally converted into mechanical or electrical energy.

B.P. 795,028. Radioactive oil production. To: Bendix Aviation Corp. (U.S.A.).

Oils containing radioactive substances (tracer oils) are readily detected, even in minute quantities and in inaccessible locations but tracer oils are limited in variety, expensive and relatively short-lived owing to the limited half-life of the radioactive isotope. The radioactive substance to be incorporated is obtainable from plants under the control of the Atomic Commission and any available radioactive isotopes in aqueous solution may be used in the new process. Alcohol is added to this solution. Oil and the aqueous alcohol solution are emulsified and clarified with a dispersant. Alcohol, water and dispersant are then removed by heating to above the boiling point of the components but remaining below the boiling point of the oil.

The costs can thus be reduced to a fifth of the present price, a wide variety of oils can be used and the half-life may be increased from, e.g., 8 days for radioactive iodine to 2.3 years for radioactive caesium.

B.P. 795,036. Apparatus for detecting ionizing radiation. To: Philips Electrical Industries, Ltd. (U.S.A.).

Because of the production of two types of output pulses, main pulses and escape pulses, it has often been impossible to obtain accurate results or to distinguish between the two types. The new apparatus works with two detector tubes one of which is exposed to the primary radiation to be detected and is capable of emitting escape radiation, while the second tube is exposed to this escape radiation but screened from the primary radiation. Both tubes produce in response to the ionizing radiation electrical indications which appear on an output terminal individual to that tube but connected to a utilization circuit common to the two tubes and adapted for comparing the outputs.

B.P. 795,406. Nuclear reactors. H. R. C. Pratt. To: U.K. Atomic Energy Authority.

Boiling-water reactors in which the coolant also acts as a moderator suffer from fluctuations in the power output, owing to ebullition. In order to keep the coolant density in the core constant, the vertical fuel elements are set in coolant tubes with an annular space between the smooth outer face of the element and the inner wall of the tube. The shape and dimensions are so chosen that a smooth continuous surface is provided for the support of a climbing film of liquid when the reactor is in operation with the coolant under a certain pressure fed at a certain rate. Towards the upper end of the tube where the climbing film ceases and only the vapour phase remains in the tube, ceramic fuel elements are provided which can be allowed to run dry and superheat the vapour.

B.P. 795,421. Performance of nuclear fission reactions and apparatus therefore. To: Stichting Reactor Centrum Nederland (Netherlands).

In a reactor system employing a suspension of solid fissile material in a moderating carrier liquid (ordinary or heavy water) it is desirable to maintain a predetermined concentration of the fuel suspension in every part of the reactor vessel. A good control has been achieved by a regulated downward flow of the suspension as described in B.P. 783,985 (Stichting Reactor Centrum Nederland). It has now been found that good control is also possible if the suspension is circulated upwardly through a reactor with vertical passages of uniform cross-section provided the suspension is kept in laminar flow and the velocity of the carrier liquid and the concentration of the fissile material is appropriately controlled. The velocity of the upward liquid flow must be greater than the settling rate of the fissile material in a static body of the liquid. The concentration of the suspension need not be uniform over the horizontal cross-section of the vessel. The essential condition is that it is vertically constant at any place across the vessel.

B.P. 795,511. Lowering mechanism. G. E. Lockett. To: U.K. Atomic Energy Authority.

The velocity of a falling weight is controlled by an energy absorbing device (flywheel driven through a free-wheel device) so that the weight falls quickly at first, then after reaching a velocity peak travels at a reduced rate until most of its kinetic energy has been taken up by the rotating flywheel.

B.P. 795,565. Control mechanisms for nuclear reactors. G. E. Lockett. To: U.K. Atomic Energy Authority.

The rod control is effected by a drive nut on a hollow threaded shaft. The shaft is connected to the control rod by an electromagnet on the shaft and an armature on the rod. The drive nut is driven through a clutch capable of slipping when the nut is arrested. On releasing the coupling between rod and shaft the control rod falls under gravity into a " shut-off " position.

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